The Institute Letter

Institute for Advanced Study

Fall 2011

Robbert Dijkgraaf Appointed IAS Director

HENK THOMAS

Robbert Dijkgraaf

On November 14, the Institute for Advanced Study announced the appointment of Robbert Dijkgraaf as its ninth Director, succeeding, as of July 1, 2012, Peter Goddard, who has served as Director since January 2004.

A former Member (1991–92) and Visitor (2002) in the School of Natural Sciences, Dijkgraaf will bring broad expertise to the role as a leading theoretical and mathematical physicist and a distinguished administrator and advocate for science and the arts. Currently President of the Royal Netherlands Academy of Arts and Sciences and Distinguished University Professor of Mathematical Physics at the University of Amsterdam, Dijkgraaf has recognized deep connections between physics and mathematics and has found powerful applications of ideas within mathematical physics that have furthered the development of string theory and quantum field theory (see box by Edward Witten, page 13).

Below, Dijkgraaf speaks about his enthusiasm for the Institute and for using knowledge, creativity, and collaboration to further our understanding of a world of diverse facts, structures, ideas, and cultures.

I am delighted to come to the Institute for Advanced Study, one of the intellectual centers of the world. The position of Director is highly distinguished, and the list of former Directors is quite intimidating. But I am particularly looking forward to combining at the highest level three elements that have been important in my professional life: the opportunity to collaborate with the very best scientists and scholars; to organize a stimulating environment for great talent from around the world; and to play an active role in science education, advocacy, and diplomacy to engage future generations.

Taking up my appointment as Director of the Institute will feel a bit like coming home. My family and I have only the best recollections of our stays in Princeton. I also expect that in many ways my life will become more focused. My present position as President of the Royal Netherlands Academy of Arts and Sciences requires giving attention to many different areas, from elementary school programs to industrial affairs, from government policy to international relations. The Institute is remarkably effective as a place for concentration and inspiration.

As envisioned by the founders, the Institute has an absolutely unique place in the intellectual landscape. Not only does it bring academics of the highest level together, it is also a symbol across the world for the importance of undirected research. At the Institute, "it" can happen, although nobody will or can tell you in advance what "it" is. Unfortunately, places that allow such unrestricted academic freedom are becoming more rare, since so much emphasis today is on short-term returns. The Trustees must be complimented that they have kept this clear vision intact over the years.

The Institute is a magical place. But just like magic on the stage, this kind of magic requires a lot of effort behind the scenes! The Institute tries to create an atmosphere that inspires scholars to take their research to the next level. Former Director Robert Oppenheimer liked to use the word "inspiriting." Of course, the list of great scholars associated with the Institute is remarkable, but this impressive history does not seem to weigh people down. Instead, the atmosphere focuses on the here and now. What are you thinking about right now? And how can you engage your colleagues in this adventure?

My first visit to the Institute was as a graduate student in 1988. I still remember driving at night along Olden Lane and seeing Fuld Hall fully lit from a distance. I felt like I was entering a new world, as if, in some way, I had to start all over again. That visit led to my first paper written with Edward Witten, on three-manifold invariants from finite groups. I subsequently came as a postdoc to Princeton University, but continued my collaboration

(Continued on page 13)

Morals and Moralities
A Critical Perspective from the Social Sciences

BY DIDIER FASSIN

The Good Samaritan, *Rembrandt van Rijn*

Philosophers have always been interested in moral questions, but social scientists have generally been more reluctant to discuss morals and moralities. This is indeed a paradox since the questioning of the moral dimension of human life and social action was consubstantial to the founding of their disciplines.

A clue to this paradox resides in the tension between the descriptive and prescriptive vocations of social sciences: is the expected result of a study of moralities a better understanding of social life, or is the ultimate goal of a science of morals the betterment of society? At the beginning of the twentieth century, the German sociologist Max Weber, following the first line, pleaded for a value-free study of value-judgment, examining, for instance, the role played by the Protestant ethic in the emerging spirit of capitalism. His French contemporary Emile Durkheim, more sensitive to the second option, strongly believed that research on morality would not be worth the labor it necessitates were scientists to remain resigned spectators of moral reality, a position that did

(Continued on page 4)

Can the Continuum Hypothesis be Solved?

BY JULIETTE KENNEDY

ORREN JACK TURNER/INSTITUTE FOR ADVANCED STUDY

The continuum hypothesis was under discussion as an "undecidable statement" at the Princeton University Bicentennial Conference on "Problems of Mathematics" in 1946, the first major international gathering of mathematicians after World War II. Kurt Gödel is in the second row, fifth from the left.

In 1900, David Hilbert published a list of twenty-three open questions in mathematics, ten of which he presented at the International Congress of Mathematics in Paris that year. Hilbert had a good nose for asking mathematical questions as the ones on his list went on to lead very interesting mathematical lives. Many have been solved, but some have not been, and seem to be quite difficult. In both cases, some very deep mathematics has been developed

(Continued on page 10)

News of the Institute Community

ANGELOS CHANIOTIS, Professor in the School of Historical Studies, has edited *Ritual Dynamics in the Ancient Mediterranean: Agency, Emotion, Gender, Representation* (Franz Steiner Verlag, 2011). The volume assembles approaches to rituals in several cultures of the ancient Mediterranean from the second millennium B.C.E. to late antiquity.

University of California Press has published *Humanitarian Reason: A Moral History of the Present* by DIDIER FASSIN, James D. Wolfensohn Professor in the School of Social Science. Originally published in French (Hautes Études–Gallimard–Seuil, 2010), the book explores the meaning of humanitarianism in the contexts of immigration and asylum, disease and poverty, and disaster and war.

JONATHAN ISRAEL, Professor in the School of Historical Studies, has published *Democratic Enlightenment: Philosophy, Revolution, and Human Rights, 1750–1790* (Oxford University Press, 2011), in which he demonstrates that the Enlightenment was an essentially revolutionary process, driven by philosophical debate.

ERIC S. MASKIN, Albert O. Hirschman Professor in the School of Social Science, has accepted a position at Harvard University, effective January 1, 2012. Maskin has served on the Faculty of the Institute since 2000.

Duke University Press has published *The Fantasy of Feminist History*, a collection of essays by JOAN WALLACH SCOTT, Harold F. Linder Professor in the School of Social Science, in which she argues that feminist perspectives on history are enriched by psychoanalytic concepts, particularly fantasy. *The Question of Gender: Joan W. Scott's Critical Feminism*, edited by Judith Butler and Elizabeth Weed, has been published by Indiana University Press. The volume explores the ongoing influence of Scott's agenda-setting work in history and other disciplines.

EDWARD WITTEN, Charles Simonyi Professor in the School of Natural Sciences, has been awarded the Solomon Lefschetz Medal by the Mathematical Society of Mexico.

HEINRICH VON STADEN, Professor Emeritus in the School of Historical Studies, was awarded an honorary doctorate by the Université Paris-Sorbonne at ceremonies held in Paris in June.

Palgrave Macmillan has published *Interpreting Clifford Geertz: Cultural Investigation in the Social Sciences*, edited by Jeffrey C. Alexander, Philip Smith, and Matthew Norton. The volume examines the work of CLIFFORD GEERTZ, a member of the Faculty in the School of Social Science from 1970 until his death in 2006. It reflects the breadth of his influence, looking at Geertz as a theorist rather than as an anthropologist.

MARTIN REES, an Institute Trustee and former Member (1969–70, 1973, 1975, 1982, 1992–93, 1996) in the School of Natural Sciences, has published *From Here to Infinity: Scientific Horizons* (Profile Books Ltd, 2011). Based on his 2010 Reith Lectures for BBC Radio 4, the book explores the place of science in the twenty-first century. Rees is Master of Trinity College, University of Cambridge, where he is Professor Emeritus of Cosmology and Astrophysics.

JOHN CARDY, former Member (2003, 2004) in the School of Natural Sciences, shared the 2011 Dirac Medal and Prize with Edouard Brezin and Alexander Zamolodchikov. Presented by the International Centre for Theoretical Physics, the prize recognized the three for their independent pioneering work in field theoretical methods to study critical phenomena and phase transitions. Cardy is a Professor of Theoretical Physics at the University of Oxford.

JESSICA R. CATTELINO, former Member (2008–09) in the School of Social Science, has received the Cultural Horizons Prize of the Society for Cultural Anthropology for her article "The Double Bind of American Indian Need-Based Sovereignty" in *Cultural Anthropology* 25 (2010). Cattelino is Associate Professor of Anthropology at the University of California, Los Angeles.

CÉCILE DEWITT-MORETTE, former Member (1948–50) in the School of Mathematics, has been promoted to Officier de la Légion d'Honneur. She is currently the Jane and Roland Blumberg Centennial Professor Emerita at the University of Texas at Austin.

KRISTEN GHODSEE, former Member (2006–07) in the School of Social Science, has been awarded the 2011 William A. Douglass Prize in Europeanist Anthropology by the Society for the Anthropology of Europe. Ghodsee, John S. Osterweis Associate Professor of Gender and Women's Studies at Bowdoin College, was honored for her book *Muslim Lives in Eastern Europe: Gender, Ethnicity, and the Transformation of Islam in Postsocialist Bulgaria* (Princeton University Press, 2009). The book has also received the Bulgarian Studies Association's 2011 John D. Bell Memorial Book Prize, and the Davis Center Book Prize in Political and Social Studies from the Association for Slavic, East European, and Eurasian Studies.

THOMAS HEGGHAMMER, former Member (2009–10) in the School of Historical Studies, has been awarded the Young Scholar of the Year Award of the Royal Norwegian Society of Sciences and Letters. He also received the silver medal of the Council on Foreign Relations Arthur Ross Book Award for *Jihad in Saudi Arabia: Violence and Pan-Islamism since 1979* (Cambridge University Press, 2010). Hegghammer is Senior Research Fellow and Director of Terrorism Studies at the Norwegian Defence Research Establishment.

DAVID KRAKAUER, former Member (2002–03) in the School of Natural Sciences, has been named Director of the Wisconsin Institute for Discovery. Krakauer was formerly Professor at the Santa Fe Institute.

ALAN B. KRUEGER, former Member (2007–08) in the School of Social Science, has been named by U.S. President Barack Obama to head the Council of Economic Advisers.

LILIA LABIDI, former Member (1995–96) in the School of Social Science, has been named Minister of Women's Affairs in the Government of National Unity in Tunisia. She was formerly Professor of Anthropology and Psychology at the University of Tunis.

LAURE MURAT, former Member (2005–06) in the School of Social Science, has been awarded the Prix Femina in nonfiction for her book *L'Homme Qui Se Prenait Pour Napoléon: Pour une Histoire Politique de la Folie* (Gallimard, 2011). Murat is Associate Professor of French and Francophone Studies at the University of California, Los Angeles.

SAUL PERLMUTTER, former Member (2011) in the School of Natural Sciences, has been awarded the 2011 Nobel Prize in Physics for his work on the accelerating expansion of the universe. Perlmutter, who is Professor of Physics at the University of California, Berkeley, and Faculty Senior Scientist at Lawrence Berkeley National Laboratory, shares the prize with Adam G. Riess and Brian P. Schmidt.

CHRISTINE PROUST, former Member (2009) in the School of Historical Studies, was awarded the Paul Doistau-Émile Blutet Prize in Information Science by the French Academy of Sciences. Proust is Director of Research at Laboratoire SPHERE, affiliated with Université Paris-Diderot and CNRS.

QUENTIN SKINNER, former Member in the School of Historical Studies (1974–75) and the School of Social Science (1976–79) has been awarded an honorary doctorate by the University of Oslo in connection with the University's celebration of its two hundredth anniversary. Skinner is currently Barber Beaumont Professor of the Humanities at Queen Mary, University of London.

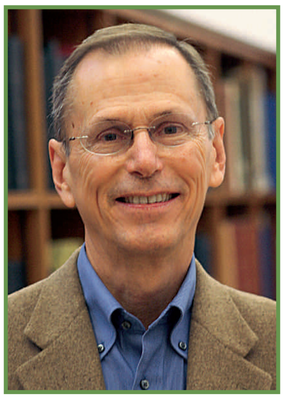
S. R. SRINIVASA VARADHAN, former Member (1991–92) in the School of Mathematics, has been awarded the National Medal of Science for his work in probability theory. The National Medal of Science is the highest scientific honor bestowed by the United States government. Varadhan is currently a Professor of Mathematics at New York University.

Contents

Questions and comments regarding the *Institute Letter* should be directed to Kelly Devine Thomas, Senior Publications Officer, via email at kdthomas@ias.edu or by telephone at (609) 734-8091.

Issues of the *Institute Letter* and other Institute publications are available online at www.ias.edu/about/publications.

Patrick J. Geary Appointed to School of Historical Studies Faculty



KATHERINE BELYI

Patrick Geary

Patrick J. Geary, a leading historian of the Middle Ages whose research has opened new ways to understand, interpret, and define the medieval past, has been appointed to the Faculty of the School of Historical Studies at the Institute, effective January 1, 2012. He succeeds Professor Emerita Caroline Walker Bynum, who has served on the Faculty of the School since 2003.

A Member in the School in 1990–91, Geary comes to the Institute from the University of California, Los Angeles, where he has been Distinguished Professor of History since 2004. Geary's scholarship extends over a vast range of topics, both chronologically and conceptually, and his work has pushed the boundaries of the field in significant and influential ways.

"We are delighted that Patrick Geary will be joining our Faculty," said Peter Goddard, Director of the Institute. "He will continue in the Institute's long and distinguished tradition of medieval scholarship, and the exceptional range, depth, and innovative nature of his research will contribute greatly to the work of our School of Historical Studies."

Nicola Di Cosmo, Luce Foundation Professor in East Asian Studies in the School, further noted that Geary "will bring to the School the rigor, creativity, and intellectual incisiveness that have characterized his work for decades and gained him a stellar international reputation. With Geary, a scholar at the pinnacle of his field, medieval studies at the Institute will continue to thrive."

Currently, Geary is leading a major project that studies the migration of European societies north and south of the Alps through the analysis of ancient DNA in Longobard cemeteries in Hungary and Italy. He also directs the St. Gall Plan Project, an Internet-based initiative funded by the Andrew W. Mellon Foundation that provides tools for the study of Carolingian monasticism.

"I am enormously honored to be given the opportunity to continue my research in this unique institution, in the community of its extraordinary Faculty and Members, selected from the leading scholars and scientists in the world," said Geary of his appointment.

Geary's first book, *Furta Sacra: Thefts of Relics in the Central Middle Ages* (1978), examines monastic narratives about stolen relics in order to explore the function of saints and relics in medieval communities and is still widely regarded. *Aristocracy in Provence: The Rhône Basin at the Dawn of the Carolingian Age* (1985) explores the world of the French aristocracy through the lens of the testament of a regional aristocrat dating to 739, advancing our understanding on landholding, kinship, and ethnicity among eighth-century Franks. In *Phantoms of Remembrance* (1994), Geary studied the preservation and destruction of memory among monastic communities, presenting a series of insightful analyses of the intersection of oral and written traditions, memory and forgetting. *Before France and Germany: The Creation and Transformation of the Merovingian World* (1986) illuminates the transformation of the Franks in the post-Roman period and challenges the later national myths of France and Germany. In the aftermath of the Yugoslavian civil war, Geary wrote *The Myth of Nations: The Medieval Origins of Europe* (2002), subsequently translated into eleven languages, a sweeping study arguing that ethnic nationalism has always been rooted in myth rather than history. Many of Geary's articles also remain standard literature in the field, for instance "Ethnic Identity as a Situational Construct in the Early Middle Ages" (1983) and "Vivre en Conflit dans une France sans État: Typologie des Mécanismes de Règlement des Conflits (1050–1200)" (1985).

From 1968 to 1969, Geary studied at the Institut Supérieur de Philosophie of the Université Catholique de Louvain in Belgium. In 1970, he received an A.B. in

(Continued on page 14)

Neil A. Chriss Appointed to Board of Trustees

Neil Chriss

The Institute has appointed Neil A. Chriss to its Board of Trustees, effective December 6, 2011. Chriss is Founder, Managing Principal, and Chief Investment Officer of Hutchin Hill Capital. He is a founding board member of Math for America, established in 2004 to improve mathematics education in public secondary schools in the United States. A former Member (1994–95) in the Institute's School of Mathematics, he is the Chair of the School of Mathematics Council, which raises awareness of the School and its work beyond the Institute community.

Chriss received a B.S. in Mathematics from the University of Chicago. He went on to earn an M.S. in Mathematics from the California Institute of Technology and a Ph.D. in Mathematics from the University of Chicago in 1993. Chriss began his career in 1993 in the Department of Mathematics at the University of Toronto. In 1996, he was a postdoctoral fellow at Harvard University. From there, he joined the Quantitative Research Group at Morgan Stanley, where he remained until 1998, at which point he became Portfolio Manager in the Quantitative Strategies Group at Goldman Sachs Asset Management. From 2000–03, Chriss was President of ICor Brokerage, Inc., and from 2003–07, he was Managing Director and Head of Quantitative Strategies at SAC Capital Management.

"Neil Chriss has been a valued supporter of the work of the Institute through his membership on our Investment Committee and his leadership of our School of Mathematics Council," said Peter Goddard, Director of the Institute. "A former Member of the Institute, he is totally committed to its mission of supporting fundamental research in the sciences and humanities."

In addition to serving on the Executive Committee of Math for America, Chriss is an Advisory Director of the Financial Mathematics Program at the University of Chicago, is on the Visiting Committee of the University of Chicago's Physical Sciences Division, and serves on the Boards of Trustees of Harvey Mudd College and the Mathematical Sciences Research Institute. ■

Richard Taylor Joins School of Mathematics Faculty

CLIFF MOORE

Richard Taylor

Richard Taylor has been appointed to the Faculty of the School of Mathematics at the Institute for Advanced Study, with effect from January 1, 2012. Taylor comes to the Institute from Harvard University, where he was the Herchel Smith Professor of Mathematics.

Taylor, a leader in number theory, and his collaborators have developed powerful new techniques that they have used to solve important longstanding problems. Taylor has been a Distinguished Visiting Professor in the School of Mathematics at the Institute since 2010.

"Richard Taylor is one of the world's leading number theorists," said Peter Goddard, Director of the Institute. "His appointment will continue work that has been pioneered at the Institute through the work of eminent mathematicians such as Hermann Weyl, André Weil, Harish Chandra, Robert Langlands, and Pierre Deligne. We are delighted that he will be joining our Faculty."

Taylor received his B.A. from the University of Cambridge in 1983 and his Ph.D. from Princeton University, where his adviser was Andrew Wiles, now Royal Society Research Professor at the University of Oxford, who has been a Member in the Institute's School of Mathematics several times since 1981 and a member of the Institute's Board of Trustees since 2007. Together with Wiles, Taylor developed a fundamental and unexpected new method to show that certain Galois representations correspond to elliptic modular forms. Now known as the Taylor-Wiles method, the pair used it to help complete the proof of Fermat's last theorem, published in 1995. Taylor went on to apply the method to a series of well-known and difficult problems. For example, together with Fred Diamond, Brian Conrad, and Christophe Breuil he resolved completely the Shimura-Taniyama-Weil conjecture in the theory of elliptic curves. With Michael Harris, he proved the local Langlands conjecture. More recently, Taylor established the Sato-Tate conjecture, another longstanding problem in the theory of elliptic curves.

"Taylor has few equals in terms of solving some of the most difficult problems in mathematics," said Peter Sarnak, Professor in the School of Mathematics. "As a natural leader who has mentored many stellar students and postdoctoral fellows, he will be a valuable addition to the Faculty of the School of Mathematics at the Institute."

Taylor was a Royal Society European Exchange Fellow at the Institut des Hautes Études Scientifiques in Paris in 1988–89. From 1988 to 1995, he was a Fellow of Clare College and successively an Assistant Lecturer, Lecturer, and Reader in the University of Cambridge. Taylor was a Visiting Assistant Professor at California Institute of Technology in 1992; Visiting Professor at Harvard University in 1994; and Miller Visiting Professor at the University of California, Berkeley, in 1999. In 1995, he was elected to the Savilian Professorship of Geometry in the University of Oxford and a Fellowship of New College. Taylor joined Harvard University as a Professor of Mathematics in 1996 and was named the Herchel Smith Professor of Mathematics in 2002. He has been a Fellow of the Royal Society of London since 1995.

Among Taylor's many awards are the 2007 Shaw Prize, shared with Professor Emeritus Robert Langlands; the 2007 Clay Research Award; the Academy of Sciences at Göttingen's 2005 Dannie Heineman Prize; the American Mathematical Society's 2002 Frank Nelson Cole Prize in Number Theory, shared with Henryk Iwaniec, Member (1983–84, 1986–88, 1999–2000) in the School of Mathematics; the 2001 Fermat Prize, shared with Wendelin Werner; and the 2000 Ostrowski Prize, shared with Iwaniec and Peter Sarnak.

"I am honored, excited, and somewhat daunted to join the extraordinary Faculty at the IAS," said Taylor. "My visit to the IAS last year was a wonderful, and productive, opportunity for renewal, after several years when my other duties had been allowing less and less time for research. I hope to have the wisdom to continue to benefit myself from the unique environment at the IAS and to help many other mathematicians do the same." ■

not prevent him from proposing a rigorous explanation of why we obey collective rules. This dialectic between exploring norms and promoting them, between analyzing what is considered to be good and asserting what is good, has thus been at the heart of the social sciences ever since their birth.

For anthropology, the problem was even more crucial, since the confrontation with other cultures, and therefore other moralities, led to an endless discussion between universalism and relativism. Given the variety of norms and values across the globe and their transformation over time, should one affirm that some are superior or accept that they are all merely incommensurable? Most anthropologists, from the American father of culturalism, Franz Boas, to the French founder of structuralism, Claude Lévi-Strauss, adopted the second approach, certainly reinforced by the discovery of the historical catastrophes engendered by ideologies based on human hierarchy, whether they served to justify extermination in the case of Nazism, exploitation for colonialism, or segregation with apartheid. This debate was recently reopened with issues such as female circumcision (renamed genital mutilation) and traditional matrimonial strategies (requalified as forced marriages), with many feminists arguing in favor of morally engaged research when it came to practices they viewed as unacceptable.

Considering these difficulties, scientific but also political and ethical, it is all the more remarkable that the social sciences have reinvested in the field of morals and moralities during the past decade. This evolution reflects a broader trend in contemporary societies where moral issues have become central in the public sphere, to the point that most domains of activity have become concerned with moral evaluations and justifications. Human rights have entered the space of international relations, military operations have been presented as humanitarian wars, bioethics has redefined the boundaries of medical research, greed in finance has been denounced as unethical, compassion has become a political virtue, poverty has been assessed according to merit. Under these changing circumstances, the growing public presence of moral questions could no longer be ignored by the social scientists, whose expertise was even on occasion solicited.

Detailed information on this research can be found on the website http://morals.ias.edu/, including corresponding publications, seminar programs, and related bibliographies.

Here, it is important to understand the profound theoretical and methodological difference between social sciences and philosophy, but also increasingly the evolutionary and cognitive sciences in their respective approaches to moral problems. Philosophers, biologists, and psychologists proceed by reduction—typically to pure moral dilemmas, generally leading to simple alternatives that do not reflect reality but formalize it in order to produce conceptualization. In this vein, evolutionary and cognitive scientists recently have proposed a universal moral grammar, which can be seen as the elementary forms of moral judgments and moral sentiments. By contrast, sociologists, anthropologists, and historians deal with complex and impure situations—because this is the reality of human life and social action. The lines between moral issues and political, economic, religious, legal, aesthetic, and social questions are often blurred. Social scientists know through their observations that there is no universal morality. Even murder can be condemned or praised, according to cultural environments, historical moments, and specific contexts.

Is the expected result of a study of moralities a better understanding of social life, or is the ultimate goal of a science of morals the betterment of society?

It is to apprehend this complexity and impurity of morals and moralities in contemporary societies that the program "Towards a Critical Moral Anthropology," funded by the European Research Council, was conceived. This collaborative project brings together a group of twelve sociologists, anthropologists, and political scientists. It is being developed on both sides of the Atlantic: in Paris, at the École des Hautes Études en Sciences Sociales, and in Princeton, at the Institute for Advanced Study, taking advantage of the presence of members simultaneously exploring similar questions through different objects. It has both a theoretical and an empirical dimension. On the one hand, it proposes a critical inquiry into the new field of the anthropology of morals and moralities, relating moral issues to their historical formation and political background. On the other hand, it includes a study of the way immigrants and minorities are treated by institutions such as the police, justice, prison, social work, and the mental health system in France, articulating the moral economy of these issues at the national level and the moral work of the social agents in their respective institutions.

ANDREA KANE

Didier Fassin, the James D. Wolfensohn Professor in the School of Social Science since 2009, is an anthropologist and a sociologist who has conducted field studies in Senegal, Ecuador, South Africa, and France. Trained as a physician in internal medicine and public health, he dedicated his early research to medical anthropology, illuminating important issues about the AIDS epidemic, social inequalities in health, and the changing landscape of global health. More recently, he has explored the relationships between the moral and the political, analyzing the reformulation of injustice and violence as suffering and trauma, the expansion of an international humanitarian government, and the contradictions in the contemporary politics of life.

Indeed, immigrants and minorities represent, in many societies, the most marginalized, stigmatized, and discriminated against. The institutions with which they deal are in part repressive (police, justice, prison) and in part rehabilitative (social work, mental health). In both cases, the technical matter of each profession (law,

(Continued on page 5)

Humanitarian Reason: A Moral History of the Present

In the aftermath of the 2004 tsunami in Southeast Asia, Clifford Geertz commented with melancholy ... that "fatality on such a scale, the destruction not only of individual lives but of whole populations of them, threatens the conviction that perhaps most reconciles many of us, insofar as anything this-worldly does, to our own mortality: that, though we ourselves may perish, the community into which we were born, and the sort of lives it supports, will somehow live on." One could extend this profound insight by suggesting that the significance of such a fatality is not only about our mourning of a possibly lost world, of which all traces may even disappear; it is also about our sense of belonging to a wider moral community, whose existence is manifested through the compassion toward the victims. For the attentive observer of the tsunami, the impressive magnitude of the toll, with its tens of thousands of casualties, was as meaningful as the unparalleled deployment of solidarity, with its billions of dollars of aid. We lamented their dead but celebrated our generosity. The power of this event resides in the rare combination of the tragedy of ruination and the pathos of assistance. . . . The moral landscape thus outlined can be called humanitarianism. Although it is generally taken for granted as a mere expansion of a supposed natural humaneness that would be innately associated with our being human, humanitarianism is a relatively recent invention, which raises complex ethical and political issues. . . .

The year 2010 began with the dreadful earthquake in Haiti, which precipitated a remarkable mobilization worldwide, particularly from France and the United States. We witnessed in fact a competition between the two countries, whose governments and populations rivaled each other in solicitude toward the victims, bounteously sending troops, physicians, goods, and money, while raising the suspicion of the pursuit of goals other than pure benevolence toward a nation that was successively oppressed by the former and exploited by the latter. This emulation was certainly triggered by goodwill, and one should not minimize the altruistic engagement and charitable efforts of individuals, organizations, churches, and even governments involved in the treatment of the injured and later in the reconstruction efforts. Yet one cannot avoid thinking how rewarding was this generosity. For a fleeting moment we had the illusion that we shared a common human condition. We could forget that only 6 percent of Haitian asylum seekers are granted the status of refugee in France, representing one of the lowest national rates, far behind those coming from apparently peaceful countries, or that thirty thousand Haitians were on the deportation lists of the U.S. Immigration and Customs Enforcement Agency. The cataclysm seemed to erase the memories of the French and subsequent American exploitation of the island. Our response to it signified the promise of reparation and the hope for reconciliation.

In contemporary societies, where inequalities have reached an unprecedented level, humanitarianism elicits the fantasy of a global moral community that may still be viable and the expectation that solidarity may have redeeming powers. This secular imaginary of communion and redemption implies a sudden awareness of the fundamentally unequal human condition and an ethical necessity to not remain passive about it in the name of solidarity—however ephemeral this awareness is, and whatever limited impact this necessity has. Humanitarianism has this remarkable capacity: it fugaciously and illusorily bridges the contradictions of our world, and makes the intolerableness of its injustices somewhat bearable. Hence, its consensual force.

— *Didier Fassin in* Humanitarian Reason: A Moral History of the Present *(University of California Press, 2011)*

A Community of Scholars: Impressions of the Institute for Advanced Study

A Community of Scholars: Impressions of the Institute for Advanced Study, an illustrated anthology published by Princeton University Press in November, celebrates eighty years of history and intellectual inquiry at the Institute for Advanced Study. The essays by current and former Members and Faculty convey the insights and perspectives of scholars who, collectively, have known the Institute over seven of its eight decades. The photographs by Serge J-F. Levy give a snapshot of one year, 2009–10, in the academic and social life of the Institute. More information about the book is available at www.ias.edu/about/publications/ias-photobook. Excerpts from the essays follow.

SERGE J-F. LEVY

Robert MacPherson, Hermann Weyl Professor in the School of Mathematics, outside Fuld Hall

I spent one and a half years on that first visit which, through the friends and future collaborators I made, laid the foundations for my entire subsequent career. In the aftermath of World War II, the Institute was a unique intellectual center where scholars from different countries and of different vintages were in haste to make up for lost time. It is perhaps a subjective illusion that one's own youth is a unique golden age with a concentration of talent, but the myth can turn into reality.

—Michael Atiyah, Member (multiple visits since 1955) and Professor (1969–72), School of Mathematics

The life-blood of the arts and humanities are ideas and imagination, the ability to put together and see connections between things that may not seem related at first sight. A fascination with, and talent for, lateral thinking quite possibly drives many researchers into the field in the first place, but it is not a skill that is just there—in my experience, it needs to be worked with, trained, and cultivated in order to be used productively in research. The IAS gives us the time and the intellectual freedom to do exactly that.

—Barbara Kowalzig, Member and Visitor (2007–08, 2009), School of Historical Studies

Spending time at the Institute is a mathematician's dream come true, especially when you have the chance to visit during a year dedicated to your field, when so many experts are in residence in addition to the permanent Members. I had this privilege, and it was a very important year in my career. There were inspiring lectures where the excitement of the audience was palpable, and happy hours spent discussing mathematics on the beautiful lawn at the back of the tea room, enjoying coffee and the famous Institute cookies, or in the cafeteria at the "math table" during lunch. And how can one not be inspired when thinking about mathematics in a Fields Medalist's former office?

—Chantal David, Member (2009–10), School of Mathematics

The highlight of the School of Social Science was—and still is, I believe—the Thursday Luncheon Seminar. For a German academic, it was a most unusual, almost exotic experience—and a challenging one for each speaker.… The first seminar I attended made me almost quiver. How relieved I would be if my own talk, scheduled for January, should go well! It did go well, very well, and I was simply elated. In the course of time, I learned that politeness should be welcome everywhere in daily life, except in intellectual debate. You can only learn and make progress when colleagues tell you, without mercy, what they think of your work—and then are willing to offer some help.

—Wolf Lepenies, Member (multiple visits since 1979), School of Social Science

The Institute, for us as for so many others, represents the ideal academic experience—a stimulating and collegial atmosphere with facilities designed to further scholarly work and to encourage both collaboration and innovation. Through the seminars and intellectual events it organizes, as well as through the marvelous concert series and other social events, it furthers contact, growth, and essential exchanges among scholars working in all fields, at all stages of their careers, and indeed throughout the intellectual and artistic world.

—Jane F. Fulcher, Member (2003–04), School of Historical Studies

One of my vivid memories from the [Danish astronomer Bengt] Strömgren years is the little machine that he kept in his office in Fuld Hall. He liked to sit there in the evenings feeding observational input into it and examining theoretical output. The input was accurate measurements of the brightnesses of stars in four colors. The output was pictures of the spiral arms of our galaxy at various times in the past. This was Strömgren's personal sky survey, which he carried out with the help of some visiting Institute Members and $9,800 per year from the Office of Naval Research, a modest sum even in those days. The little machine was a precursor of the personal computers that became available twenty years later.

—Freeman Dyson, Professor (since 1953, Emeritus since 1994), School of Natural Sciences

There have been artists associated with the IAS throughout its history, most notably T. S. Eliot in 1948, but it was not until 1994 that the Artist-in-Residence program was established. I consider this enlightened decision a formal acknowledgement that the creative artist's activity is a viable mode of achieving human understanding, a truly intellectual endeavor. What can the artist contribute to an intellectual community of scholars, mathematicians, and scientists (social and natural)? The art of music, for instance, cannot really explain or even theorize about anything at all, certainly not in the manner in which these other fields do. But in its mysterious, inimitable way, music can help us to know ourselves and our reality through an elegantly ordered aesthetic experience.

—Paul Moravec, Artist-in-Residence (2007–09)

Some of the best photographs in this volume show scholars at work in the Institute libraries, buried in books, surrounded by them. Even when there is only a single individual in the photograph, the collective nature of the production of knowledge is signified by the books she is consulting. The shelves behind her reinforce that notion, reminding us that learning is a process of engagement with the ideas and interpretations of many others. When Elliott Shore, then Historical Studies–Social Science librarian, proposed a library computer center in 1992, he insisted that it not intrude into the reading rooms, in order to preserve "the quality of the library as an unsurpassed haven for readers." A haven, I suggest, not in the sense of an isolated cell, but of a paradoxically silent space full of noisy interlocutors clamoring for our attention. Books, lots of them all in one place, are the not so silent players in the life of the mind.

—Joan Wallach Scott, Professor (since 1985; Harold F. Linder Professor since 2000), School of Social Science

E Building was often still crowded at 1 a.m., and sometimes the night owls would overlap with the early birds. Electronic preprints were in their early days, and the astrophysics world still ran mostly on paper. Each week, three or four blue-bound IAS astro-preprints would appear in our mailboxes, a reminder of how much our fellow postdocs were getting done. In case that wasn't encouragement enough, you could also count on Andy Gould (one of the five-year Members) marching into your office each morning and asking, "What's new?" hungry to hear your latest result or discuss his most recent idea. The intensity was high, sometimes unnerving, but mostly exciting.

—David H. Weinberg, Member (multiple visits since 1992), School of Natural Sciences

MORALITY *(Continued from page 4)*

surveillance, assistance, psychiatry) does not entirely account for the decisions made or attitudes adopted toward the public: a moral evaluation is always involved—implicitly or explicitly. Police officers, magistrates, and guards, as well as social workers and health professionals, use moral categories to disqualify or absolve, construct moral communities to exclude or include, develop moral justifications to mistreat or respect. Of course, these moral elaborations are not born from a social void. Actually, the scientific challenge is to understand how public discourses and public policies influence institutional and professional practices—and are, in turn, consolidated or sometimes reformulated through the latter. In other words, we seek to understand how the macrosocial (politics and policies) and the microsocial (beliefs and practices) are articulated—which is one of the major theoretical interrogations, if not enigmas, for social scientists.

Consider, for instance, the administrative and judicial process through which the applications of asylum seekers are assessed to determine whether or not they will be granted refugee status. In Europe, public discourse regarding so-called "bogus refugees" has progressively infiltrated the everyday work of the officers and magistrates in charge of the evaluation of the applicants. Whereas trust was common three decades ago, when nine asylum seekers out of ten were granted the precious status, suspicion has become the rule, leading to increasingly lower rates of recognition, currently down to two out of ten. In this new context, where the veracity of their accounts is very difficult to establish, the sincerity of the applicants is to a greater extent assessed through sympathy produced in reaction to their display of emotions. Paradoxically, however, the more severe the judgments are, the more convinced the judges are of their fairness. For them, the loss of credit of the asylum seekers' word has for corollary the increasing worth of asylum as an abstract principle—to the point of rendering it inaccessible. Ultimately, policy makers see their doubts concerning the veracity of accounts and the sincerity of the applicants confirmed by the low rates of recognition. Norms and values therefore circulate between the macrosocial and the microsocial, between national forums, where immigration issues are debated, and local bureaucracies, where vital decisions are made. The moral economy of asylum is thus deeply embedded in political issues and dependent on social questions.

To apprehend such interlinked scales and intertwined domains, the method of choice is ethnography, that is, the participant observation, over lengthy periods of time, of the activity of the professionals in their respective institutions: the police in the streets, the magistrates in the courts, the guards in the prisons, social workers in their administration, psychiatrists in their hospital. This means a reorientation of traditional fieldwork. Anthropologists have long studied distant and isolated ethnic groups. They have discovered that their place is also at home, where certain social worlds are perhaps no less exotic or no less misrepresented than what they used to call "primitive societies." In particular, the inquiry into morals and moralities offers the possibility to seize simultaneously the shared norms and values across social worlds and the specific rules and sensibilities that singularize each of them—a felicitous addition to what Clifford Geertz, founding Professor of the Institute's School of Social Science, regarded as the "ethical dimension of anthropological fieldwork." ■

A Quantum Story

BY JEREMY BERNSTEIN

Debates at the fifth Solvay Conference in Brussels in 1927 helped shape the modern interpretation of quantum mechanics. Participants included Niels Bohr (second row, far right) and Albert Einstein (first row, fifth from left).

BENJAMIN COUPRIE/INSTITUT INTERNATIONAL DE PHYSIQUE DE SOLVAY

In the two years I spent at the Institute, 1957–59, I had the opportunity of meeting two of the founders of the quantum theory—Niels Bohr and Paul Dirac. In the case of Bohr, perhaps "meeting" overstates the case. He was a Member in the spring of 1958 and Oppenheimer, who had known him since the 1920s and who had a feeling of adulation for him, decided that a fitting thing to do was to have a sort of seminar in which the physicists would trot out their wares with Bohr looking on and possibly commenting. As it happened, I had had a brief collaboration with T. D. Lee and C. N. Yang, who had won the Nobel Prize that fall. They had better things to tell Bohr than our modest work, so I was the designated spokesman. I was given ten minutes and took about three. After which Bohr commented, "Very interesting," which meant he did not think so. If he had had any real interest, he would have engaged in a Socratic dialogue, which would have proceeded until he was satisfied. There is a famous story concerning Erwin Schrödinger—with whom I later spent an afternoon in Vienna—arriving in Copenhagen after having created his version of the quantum theory. Bohr disagreed with some of what Schrödinger was saying and pursued him into his bedroom where the now sick Schrödinger had taken refuge.

On a visit to the Institute ten years earlier, Bohr had written his wonderful account of his discussions with Einstein about the theory. Bohr found writing incredibly difficult and always had an amanuensis who acted as a sounding board. In this case, it was Abraham Pais who told the following story. Einstein had given Bohr his office for the visit and was in the adjoining smaller office of his assistant. Where the assistant had gone is not recorded. Bohr was facing away from the door and saying, "Einstein, Einstein" several times. As if summoned by a genie, Einstein stealthy came into the office. Before Bohr could turn around, Einstein helped himself to some of Bohr's pipe tobacco. When Bohr did turn around, Einstein explained that his doctor had ordered him not to "buy" any more tobacco, but there was no injunction against his "stealing" some.

My encounters with Dirac were somewhat more extensive. In the 1958–59 terms, he had come to the Institute. On some evenings when his wife—whom he sometimes introduced as "Wigner's sister" since, in fact, she was the sister of Eugene Wigner—was out of town, he would eat his dinner with the rest of the bachelors in the Institute cafeteria. Most of us were too shy to ask him anything, but not John Sakurai, who was visiting from Cornell. We had been discussing scientific collaboration when Sakurai asked Dirac if he had ever collaborated with anyone. Dirac replied, "The really good ideas are had by only one person," which put an end to that.

Einstein asked if Pais really believed that the moon was not there when no one looked at it. Esse est percipi*—to be is to be perceived—as Bishop Berkeley famously said. The quantum umpire would argue that in some sense observables do not exist until they are observed. This is what Einstein found intolerable.*

In 1962–63, Dirac was again visiting the Institute. By this time, I had begun to write scientific profiles for the *New Yorker* and had decided that Dirac would be a very good subject. I had even conceived a modus operandi. I knew from his previous visit that Dirac spent much time in the woods behind the Institute clearing brush or chopping trees. To what end, I never found out. I thought I would join him in this enterprise and discuss his life and times as we chopped. I arranged to visit him in his office in Princeton. The one thing that stood out in that encounter was his insistence that Heisenberg be credited for the invention of quantum theory. I found this a little odd since Heisenberg's role was so well-known. But looking back I think more was involved. Many physicists had never forgiven Heisenberg for his role during the war. When he came to Cambridge to give a talk, which I attended, some of them refused to shake his hand. I think that Dirac was signaling that he did forgive Heisenberg. In any event, after my visit, Dirac put a stop to the project. At the time, I was disappointed, but looking back I am grateful. I would never have found out enough about him to write a good profile.

In 1929, Dirac famously said of the then recently invented quantum theory, "The underlying physical laws necessary for the mathematical theory of a large part of physics and the whole of chemistry are thus completely known, and the difficulty is only that the exact application of these laws leads to equations much too complicated to be soluble." Now, eight decades later, one would add biology, astrophysics, cosmology, and computing to the list and note that computers have made possible approximate solutions to equations that would have been beyond the capacities of the physicists at that time to deal with. Nonetheless, there were reservations about the theory, especially by Einstein, from the beginning. In 1925, he wrote to his friend from the patent office, Michele Besso (my translation), "The most interesting recent delivery by the theorists is the theory of Heisenberg-Born-Jordan concerning the quantum situation. A veritable sorcerers' calculation in which there appear infinite determinants (matrices) in the place of Cartesian coordinates. This is sufficiently ingenious and protected by its great complexity, to be immune to any proof of its falsity." Schrödinger's wave mechanical version of the theory had not yet been discovered. When it

APPENDIX: *Spinning*

In the body of the text, I mentioned some of the consequences of rotating the Stern-Gerlach magnets. In this appendix, I want to fill in the details. We imagine first performing measurements of the spin along the *z*-axis when the particles are moving in the y direction. We then rotate the magnet through an angle θ in xz plane.

The Pauli matrix, which was $\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$

is in the new system $\begin{pmatrix} \cos(\theta) & \sin(\theta) \\ \sin(\theta) & -\cos(\theta) \end{pmatrix}$.

This matrix has the eigen vectors

$$\begin{pmatrix} \cos(\theta/2) \\ \sin(\theta/2) \end{pmatrix} \text{ and } \begin{pmatrix} -\sin(\theta/2) \\ \cos(\theta/2) \end{pmatrix}.$$

We can expand the vector $\begin{pmatrix} 1 \\ 0 \end{pmatrix}$ in this basis and write

$$\begin{pmatrix} 1 \\ 0 \end{pmatrix} = a_+ \begin{pmatrix} \cos(\theta/2) \\ \sin(\theta/2) \end{pmatrix} + a_- \begin{pmatrix} -\sin(\theta/2) \\ \cos(\theta/2) \end{pmatrix}.$$

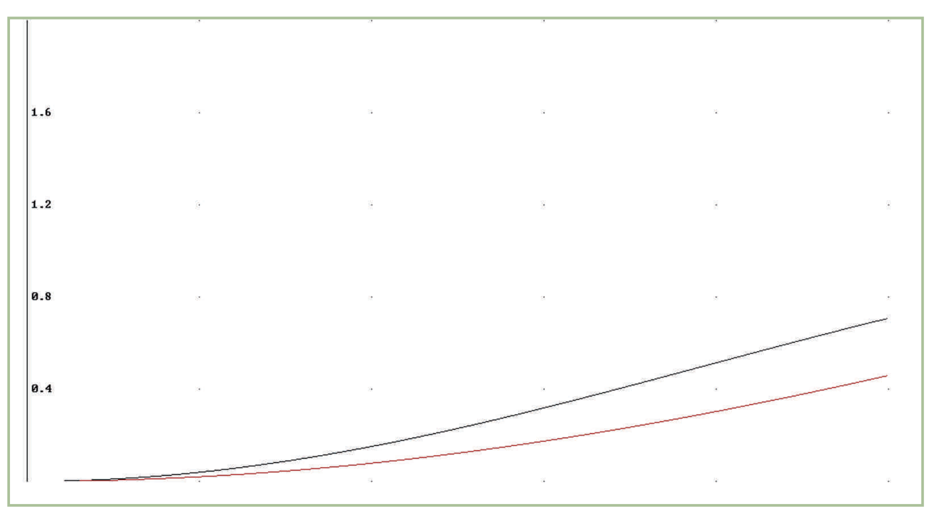
Which implies that $a_+ = \cos(\theta/2)$ and $a_- = -\sin(\theta/2)$. This means that the probability of finding the spin up in the rotated magnet is $\cos(\theta/2)^2$, while the probability of finding spin down is $\sin(\theta/2)^2$. Hence, with the entangled singlet particles, if I measure spin down (or up) in one magnet, then the probability of measuring the same result in the rotated magnet is $\sin(\theta/2)^2$, while the probability of measuring the opposite spin is $\cos(\theta/2)^2$. Thus, the quantum mechanical correlation is given by

$$\sin(\theta/2)^2 - \cos(\theta/2)^2 = -\cos(\theta).$$

Can we program the robots to reproduce this? There is no problem programming a robot, once it finds the rotated magnet, to alter its trajectory so that the two spins are aligned $\sin(\theta/2)^2$ fraction of the time, agreeing with quantum mechanics. But if both magnets are rotated in opposite directions by the same angle, then the robots will alter their trajectories so that agreement occurs $2\sin(\theta/2)^2$ of the time. But the quantum prediction is that agreement in this case occurs $\sin(\theta)^2$ percent of the time, in the range

$$0 < \theta < \pi/2,\ \sin(\theta)^2 > 2\sin(\theta/2)^2,$$

as the figure below shows. This is Bell's inequality in this simple case.



The blue line is the plot for $\sin(\theta)^2$, and the red line is the plot for $2\sin(\theta/2)^2$.

was, Einstein was initially enthusiastic until Max Born argued that the Schrödinger waves were waves of probability. This inspired Einstein to write Born in 1926,

"Quantum mechanics is certainly imposing. But an inner voice tells me that it is not yet the real thing. The theory says a lot, but does not really bring us any closer to the secret of the 'old one.' I, at any rate, am convinced that He does not throw dice."

This particular objection to the theory soon was superseded by others. By the 1930s, something called the "Copenhagen interpretation" was widely accepted and Einstein disagreed with most of it. The best, simple summary of this interpretation (which was never called that in Copenhagen—indeed, people like Léon Rosenfeld, who was Bohr's amanuensis in the 1930s, insisted that the quantum theory was not like a piece of music that *needed* an interpretation) was given by John Wheeler in terms of his three baseball umpires.

Number 1: I calls 'em like I see 'em.

Number 2: I calls 'em the way they are.

Number 3: They ain't *nothing* till I calls 'em.

Einstein is probably best described by the second umpire and Bohr by the third. Pais once walked Einstein home from his office when the moon rose. Einstein asked if Pais really believed that the moon was not there when no one looked at it. *Esse est percipi*—to be is to be perceived—as Bishop Berkeley famously said. The quantum umpire would argue that in some sense observables do not exist until they are observed. This is what Einstein found intolerable. In 1935, two years after he had joined the Institute, he coauthored a paper with Boris Podolsky and Nathan Rosen, "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete." Rosen was in his twenties and Podolsky considerably older. Einstein recruited them to come to Princeton. The paper was actually written in English by Podolsky, and Einstein was always unhappy with the way it had been written. One wonders if he had bothered to read it before it was published.

In essence, the paper deals with what I would call "implicit measurements." This is when a quantity is not measured directly, but its value is conferred on the distant object by the measurement of a related object, which may indeed be widely separated from it in space. Prior to this observation, as far as quantum mechanics was concerned, this property did not exist—Wheeler's third umpire. Einstein, Podolsky, and Rosen created a thought experiment involving the implicit measurements of positions and momenta. This, they said, conferred "reality" on these quantities. This reality must already have existed, they argued, before the measurements were made. Then they argued that Heisenberg's uncertainty principle forbade such pairs of observables to coexist, and hence, that quantum mechanics was unable to completely describe reality.

Bohr was quick to react. His response is not very easy to understand. He objected to Einstein's use of the notion of "reality" and brought into question the matter of whether such an implicit measurement does, or does not, disturb the distant object. Indeed, the entanglement of the wave functions of the system ensures in quantum mechanics that it does. What I found interesting about this discussion is that almost no one cared. I made a bit of a literature search, and for the next decade or so, I could find almost no references to this paper. This was also true of the quantum mechanics textbooks with the notable exception of David Bohm's 1951 text *Quantum Theory*. Bohm not only discussed the experiment but presented a version involving electron spins that has been with us ever since.

Bohm imagined a pair of electrons created in a state in which their spins were "entangled." This meant that their wave functions could not be written as a simple product of wave functions for each electron. As long as there is no perturbation, this entanglement endures whatever the spatial separation of the electrons. This entanglement apparently enables one to confer properties to a distant object by measurements on a nearby object—something that Einstein referred to as a "spooky" action at a distance. One can arrange a magnet to measure the component of the spin, in a certain direction, of one of the electrons and another distant magnet to measure a component of the spin of the other. If this is done for a series of such electron pairs, the results will seem to each observer to be random. But when the results are compared, one will find a correlation between the two spin components. *This* is the spooky action at a distance. You determine the spin component of the spin of the distant electron by a measurement on the nearby electron. The question is can this be "explained," meaning can one give some sort of explanation that goes beyond the usual quantum mechanics. Enter John Bell.

There is a school of thought that believes that quantum theory is a "theory of everything." For them, both the past and future are to be described as probable. The moon is overwhelmingly likely to be there when you are not observing it. Then there is a school, of which Freeman Dyson is a prominent member, that believes that the quantum theory is not a theory of everything. In particular, while one's future is probable, one's past is certain. The world is divided into patches, some of which are classical, depending on your reference point.

Bell was born in 1928 in Belfast. He died in the fall of 1990 of a cerebral aneurysm. That year, he had been nominated for a Nobel Prize. He began taking courses in quantum mechanics in the late 1940s at Queens College in Belfast. He thought that the presentations of the theory he was given were intolerable. I once asked him if, when he was learning it, he thought that the theory might actually be wrong. "I hesitated to think it might be wrong," he replied, "but I *knew* it was rotten." "Rotten" was pronounced with relish.

When Bell took his degree in 1949, he immediately went to work for the British Atomic Energy Research Establishment, designing accelerators. From time to time, he thought about quantum mechanics but as an avocation. This continued when he and Mary, his physicist wife, took jobs in 1960 at CERN in Geneva. In 1963, the Bells took a leave at Stanford University, and Bell felt free to do what he wanted. What he did was to create a test of Einstein's interpretation of the quantum theory. If Einstein had been right, not only would the quantum theory have been incomplete, it would have been simply wrong. This test—Bell's theorem—a decade or so later, became the basis of actual experiments, all of which confirmed the quantum mechanical prediction. Again pace Einstein. When this happened, Bell became well-known and was asked to give lectures to a variety of audiences about his work. I asked him what technique he used to convey these abstruse matters to people who were not physicists. He told me that he became interested in identical twins that had been separated at birth and came across the annals of something called the Institute for the Study of Twins. When these twins were finally reunited, it turned out that they had some very surprising things in common. Some had bought the same model of car. Some went to the same resort in Florida for their vacations. There was a pair that had dogs, and the dogs had the same name. I followed this up and came across a pair of American twins who, when they finally met, found that they did not like each other very much. We have an "explanation" for this. We say that the twins have identical genes. Is there something like genes for the electrons?

I made this somewhat quantitative by imagining that each electron in the entangled pair was outfitted with a miniscule "Einstein robot." These wonderful robots could guide the electrons to follow appropriate trajectories in magnetic fields. The only thing that they could not do was to communicate with each other at speeds greater than that of light. This property is sometimes called "locality," and it is a premise of Bell's argument. I found that by changing the angles between the magnetic fields of the two magnets, you could confuse the robots so that they could not reproduce the quantum mechanical correlations. In short, if there are hidden variables, nonlocality is essential. There are, for such variables, "spooky" actions at a distance. Pace Einstein. This sort of nonlocality is an essential part of the quantum theory.

At present, there is considerable interest in the foundations of the quantum theory. "Bell's theorem" is presented in many textbooks. But there is still a disagreement as to what the theory means. There is a school of thought that believes that quantum theory is a "theory of everything." For these people, the existence of the classical world is an emergent phenomenon, which has to be derived. For them, both the past and future are to be described as probable. The moon is overwhelmingly likely to be there when you are not observing it. Then there is a school, of which Freeman Dyson is a prominent member, that believes that the quantum theory is not a theory of everything. In particular, while one's future is probable, one's past is certain. The world is divided into patches, some of which are classical, depending on your reference point. Bohr insisted that experimental apparatuses be classical, but he was never very clear where the dividing line was. We don't really have experimental guidance on these matters, and, in the meanwhile, the quantum theory explains all of chemistry and most of everything else. Dyson's children, when they were very young, had the following exchange about the theory of rowing a boat. It applies to the quantum theory.

> *George*: I can understand how a boat moves along when you push on the oars. You push the water away and so it makes room for the boat to move along.
>
> *Esther*: But I can make the boat move along even without understanding it. ■

Acknowledgments

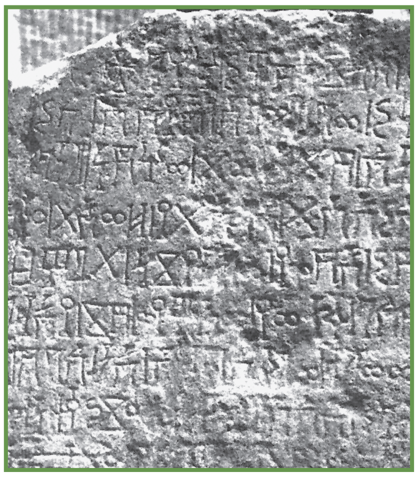
I have profited from suggestions made by Steve Berry, Arthur Fine, Ken Ford, Tim Maudlin, Cameron Reed, and Jon Rosner. Above all, I am grateful to David Mermin for his very careful reading of the manuscript and his critical remarks. *il miglior fabbro*.

Jeremy Bernstein (left, with John and Mary Bell at CERN in 1989), a Member in the School of Mathematics in 1957–59, has had a dual career in physics and writing. In addition to having been a professor of physics, he was for thirty-five years a staff writer for the New Yorker *magazine. His latest book,* Quantum Leaps *(Harvard University Press, 2009), is about the cultural implications of the quantum theory.*

The Rise and Fall of a Jewish Kingdom in Arabia

BY GLEN W. BOWERSOCK

In these turbulent times in the Middle East, I have found myself working on the rise and fall of a late antique Jewish kingdom along the Red Sea in the Arabian peninsula. Friends and colleagues alike have reacted with amazement and disbelief when I have told them about the history I have been looking at. In the southwestern part of Arabia, known in antiquity as Himyar and corresponding today approximately with Yemen, the local population converted to Judaism at some point in the late fourth century, and by about 425 a Jewish kingdom had already taken shape. For just over a century after that, its kings ruled, with one brief interruption, over a religious state that was explicitly dedicated to the observance of Judaism and the persecution of its Christian population. The record survived over many centuries in Arabic historical writings, as well as in Greek and Syriac accounts of martyred Christians, but incredulous scholars had long been inclined to see little more than a local monotheism overlaid with language and features borrowed from Jews who had settled in the area. It is only within recent decades that enough inscribed stones have turned up to prove definitively the veracity of these surprising accounts. We can now say that an entire nation of ethnic Arabs in southwestern Arabia had converted to Judaism and imposed it as the state religion.

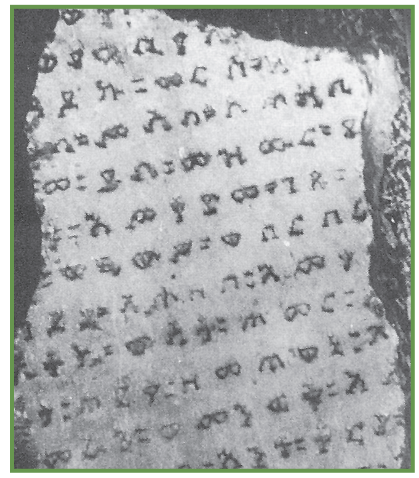


The negus Kaleb celebrated his campaign in Arabia with an inscription set up in Axum. The text is in classical Ethiopic but written in South Arabian script (right to left). Note the cross at the left end of the first line.

This bizarre but militant kingdom in Himyar was eventually overthrown by an invasion of forces from Christian Ethiopia, across the Red Sea. They set sail from East Africa, where they were joined by reinforcements from the Christian emperor in Constantinople. In the territory of Himyar, they engaged and destroyed the armies of the Jewish king and finally brought an end to what was arguably the most improbable, yet portentous, upheaval in the history of pre-Islamic Arabia. Few scholars, apart from specialists in ancient South Arabia or early Christian Ethiopia, have been aware of these events. A vigorous team led by Christian Julien Robin in Paris has pioneered research on the Jewish kingdom in Himyar, and one of the Institute's former Members, Andrei Korotayev, a Russian scholar who has worked in Yemen and was at the Institute in 2003–04, has also contributed to recovering this lost chapter of late antique Middle Eastern history.

The extraordinary history of Jewish Arabia in the sixth-century history of the Red Sea region provides an indispensable and much neglected backdrop for the collapse of the Persian empire before the Byzantines, as well as the rise of Islam.

The Institute for Advanced Study is the perfect place for research on something that cuts so dramatically across the traditional boundaries of historical studies, and my own work has been greatly enriched by Faculty and Members in Classics, Near Eastern studies, Byzantine history, and early Islam. No one can look at the kingdom of Jewish Arabia without reference to the Ethiopians at Axum in East Africa, the Byzantines in Constantinople, the Jews in Jerusalem, the Sasanian Persians in Mesopotamia, or the Arab sheikhs who controlled the great tribes of the desert. Soon after 523, all these powerful interests had to confront a savage pogrom that Joseph, the Jewish king of the Arabs, launched against the Christians in the city of Najran. Joseph himself reported in excruciating detail to his Arab and Persian allies on the massacres he had inflicted on all Christians who refused to convert to Judaism. News of his infamous actions rapidly spread across the Middle East. A Christian who happened to be present at a meeting of an Arab sheikh at which Joseph had boasted of the persecution was horrified and immediately sent out letters to inform Christian communities elsewhere. When word of the pogrom reached Axum in Ethiopia, the king there—*negus*, as he was called—seized the opportunity to rally his troops and cross the Red Sea in aid of the Arabian Christians. But his motives were less than pure, since he and his predecessor had long cherished an irredentist ambition to invade southwestern Arabia, where Ethiopians had themselves once ruled in the third century. At the same time, the *negus* was able to oblige the Byzantine emperor, who had similarly more than religious motivation for attacking the Jewish Arabs of Himyar. The Persians had been supporting the Jews, and Persia was the archrival of Constantinople for control of the lands of the eastern Mediterranean.



Kaleb set up another inscription in Arabia at Marib to celebrate his campaign. The stone is now in the San‘a Museum in Yemen. This text is in Ethiopic language and script and reads from left to right.

Yet religion undoubtedly provided the common denominator for what proved to be widespread international interference in Arabian affairs. The Ethiopians used their Christian faith to carry out a mission that not only favored their own imperialist designs but, at the same time, supported the Byzantine emperor, for whom a desire to undermine the Persian empire reinforced his Christian zeal in attacking the Arabian Jews. Both the converts and Jewish settlers from an earlier era who lived in Yathrib (the future Medina) profited from Persian sympathy, as did at least one large tribal confederation in the desert. The only losers in these diplomatic and military initiatives were the traditional Arab pagans who had survived outside Joseph's realm. They could be found farther north in the peninsula, precisely where, a half-century later, the prophet Muhammad would be born. What became the Ka‘ba of Islam had begun as the shrine of the pagan deity Hubal.

The Jewish kingdom of Arabia came to an end in 525, when the Ethiopians replaced it with a Christian kingdom of their own, but the legacy of Joseph's persecution left its traces in the Arabic, Syriac, and Greek traditions. Persian sympathy for the Jews generally continued undiminished, particularly when they themselves managed to expel the Ethiopian overlords of Himyar on the eve of Muhammad's birth, allegedly in 570 or thereabouts. By the time the Persians captured Jerusalem, it was their well-known preference for Jews that explains the enthusiasm with which the Jewish population welcomed the invaders into the city, even as they drove out and killed its Christians.

This extraordinary history of Jewish Arabia in the sixth-century history of the Red Sea region provides an indispensable and much neglected backdrop for the collapse of the Persian empire before the Byzantines as well as, obviously, the rise of Islam. ■

Glen W. Bowersock is Professor Emeritus of Ancient History in the School of Historical Studies. In April 2011, he presented this material in Jerusalem during his lectures in memory of Menahem Stern, and he will develop it further in a book, The Adulis Throne, *to be published by Oxford University Press.*

Lecture Series Explores Art and Its Spaces

Art and Its Spaces, a lecture series planned for the 2011–12 academic year, marks the fourth collaboration between the Institute for Advanced Study and Princeton University addressing contemporary issues in art history.

"This series brings together speakers with expertise in a rich variety of geographical and chronological fields to explore the interaction between things and their spaces, from museum gallery to cityscape, from the body of a vase to the prejudices of the mind," said Nathan Arrington, Assistant Professor in the Department of Art and Archaeology at the University, who is organizing the series with Yve-Alain Bois, Professor in the School of Historical Studies at the Institute.

The series began on December 5 with a lecture by Juliet Koss, Associate Professor at Scripps College, who spoke about the utopian vision of Soviet models, such as children's building blocks and architectural models. On January 24, the series will continue with "I Sell the Shadow to Support the Substance," a lecture concerning Sojourner Truth's cartes-de-visite, by Darcy Grimaldo Grigsby, Professor at the University of California, Berkeley. Martha Ward, Associate Professor at the University of Chicago, will lecture on April 3, and the series will conclude with a lecture by Mignon Nixon, Professor at the Courtauld Institute of Art, on April 17. For more information, visit www.ias.edu/news/press-releases/2011/11/18/art-and-its-spaces.

Cartes-de-visite sold by Sojourner Truth, such as the one pictured at left, will be the topic of a lecture by Darcy Grimaldo Grigsby, Professor at the University of California, Berkeley, on January 24 at 5:00 p.m. in Wolfensohn Hall.

Albert Einstein at Home, Princeton, 1946–1950

The hundredth anniversary of Einstein's birth in 1979 prompted much celebration of and reflection on Einstein's scientific and cultural legacy, including at the Einstein Centennial Symposium held at the Institute in March of that year. Shortly afterward, Herman Landshoff, a German-born photographer, created a limited-edition portfolio of photographs he had taken of Einstein in his Princeton home in the 1940s and 1950s. The Institute's libraries and archives hold two versions of this portfolio, one as it was originally presented by Landshoff to Harry Woolf, Director of the Institute from 1976–87, and one that is essentially the raw source material. The latter version of the images was recently exhibited in Simons Hall.

Landshoff asked Woolf to provide the preface to the portfolio, which follows.

HERMAN LANDSHOFF/INSTITUTE FOR ADVANCED STUDY

Landshoff took a number of photographs of Albert Einstein in the 1940s and 1950s. The photographs were taken at Einstein's home in Princeton at 112 Mercer Street.

"He can revolve in orbits opposite
The orbit of the earth and so refuse
All planetary converse. And he wears
Clothes that distinguish him from what is not
His own circumference, as first a coat
Shaped to his back or modelled in reverse
Of the surrounding cosmos and below
Trousers preserving his detachment from
The revolutions of the stars.
His hands
And face go naked and alone converse
With what encloses him …"

So wrote Archibald MacLeish about Einstein in the poem that bears his name, reaching—with the condensing compactness, the power of poetry—to capture and to portray the magical melding of genius with humanity that was Albert Einstein. The thirteen pictures which follow are Herman Landshoff's contribution to the same process. Exploiting its universal language, he brings the art of photography to bear upon the human element in the life of science as it concentrates in one great man, inviting us to observe, with MacLeish again

"When he a moment occupies
The hollow of himself and like an air
Pervades all others,"

These deep, quiet pictures, set in the simple house that was his American home are a song of their own, an obligato added to the great chorus of praise and proclamation that marked the centennial celebration of Einstein's birth in 1979. Statues and paintings, films and broadcasts, symposia and stamps (the United States chose Plate 4 of this set for its commemorative) and a spate of publications brought his presence once again to the world's attention, precipitating an inventory of intelligence and an assessment of achievement unparalleled in the history of learning. But all this public clamor is best set in place, perhaps, by these photographs of a life "far from the madding crowd." At home and at work, they are reinforced by the words he wrote in March 1955, a month before his death, paraphrasing Lessing: "das Streben nach der Wahrheit sei köstlicher als deren gesicherter Besitz," (the aspiration to truth is more precious than its assured possession).

That the countries of the mind form a contiguous geography is an ancient truth. These beautiful pictures by Herman Landshoff do demonstrate, indeed, that art and science are neighboring states. An education at the Humanistische Gymnasium in Munich (where his father had become Director of the Munich Bach Society) followed by study in the Kunstgewerbeschule led to Landshoff's initial career as a caricaturist. But normal ambitions were to vanish under the rising tide of Nazism in the thirties and Herman Landshoff saw service in the French Foreign Legion in Africa before demobilization and migration to America, where his marriage took place and his career as a photographer developed.

It is not the first time that the poet has responded sensitively and profoundly to the primary displacement and the secondary enhancement of human values under the impact of conceptual revolutions in science. Donne in the *Anatomy of the World* was concerned with man in a post-Copernican universe, and Yeats in the *Second Coming* also anticipated the loss of absolute certainty emerging from the new science.

In the same vein, this brief introduction can be brought to a close by a juxtaposition of texts from poetry and science that Einstein himself might have enjoyed.

EINSTEIN*

by Archibald MacLeish

Still he stands
Watching the vortex widen and involve
In swirling dissolution the whole earth
And circle through the skies till swaying time
Collapses crumpling into dark the stars
And motion ceases and the sifting world
Opens beneath.
When he shall feel infuse
His flesh with the rent body of all else
And spin within his opening brain the motes
Of suns and worlds and spaces.

* "Einstein" from NEW AND COLLECTED POEMS 1917–1976, by Archibald MacLeish. Copyright 1976 by Archibald MacLeish. Reprinted by permission of Houghton Mifflin Company.

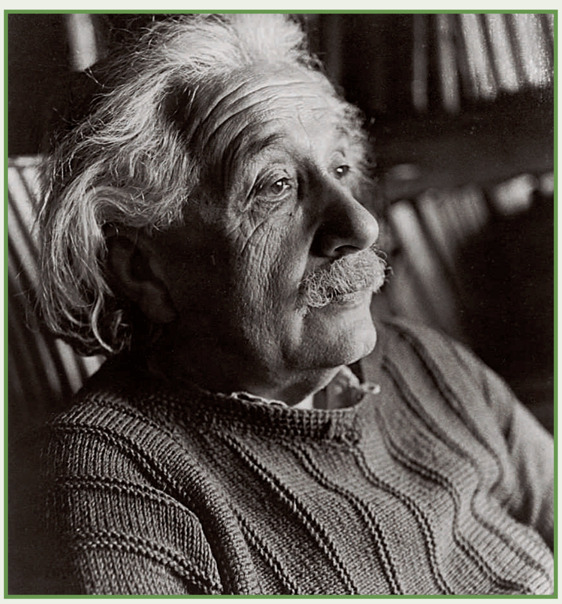
THEORETICAL ADVANCES IN GENERAL RELATIVITY**

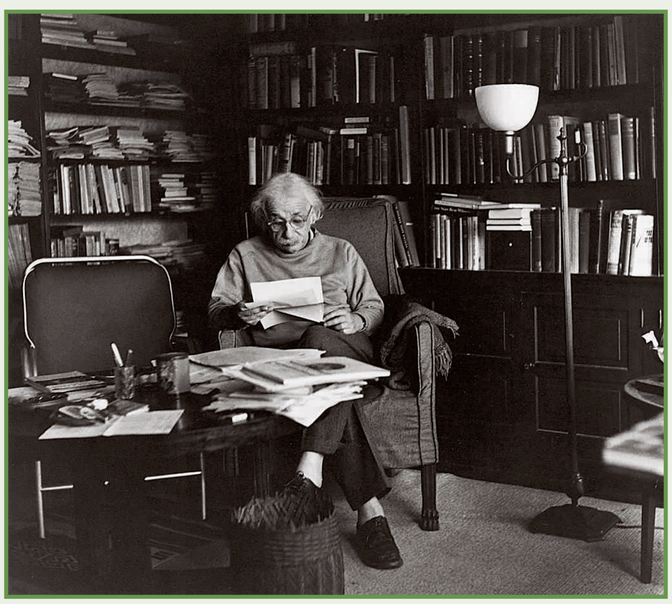
by Stephen Hawking

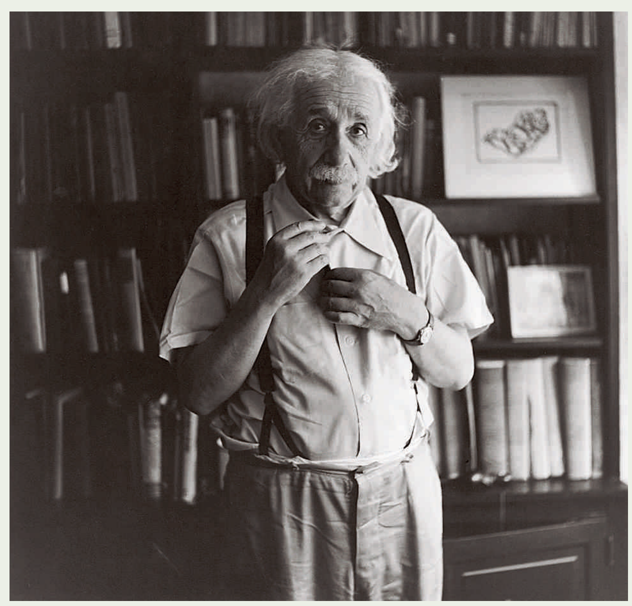
Condition 3 is the requirement of causality, i.e., that one should not be able to travel into one's own past. Thus general relativity predicts a beginning of time.

… [I]t was bad enough for time to have a beginning, but now it seemed that time would have an end as well, at least for an observer foolish or unfortunate enough to follow the collapse of a star…But we might be worried that new unpredictable information might enter the universe every time a star collapsed. Fortunately, it seems that this does not happen, at least at the classical level because it appears that the singularities formed by gravitational collapse always occur in regions of spacetime, called Black Holes, in which there is such a strong gravitational field that no light or information can escape to an external observer. This is called the "cosmic censorship hypothesis" and forms the basis for all theoretical work on Black Holes. It remains the major unproved conjecture in classical general relativity but it is supported by perturbation and computer calculations and by the failure of a number of attempts to establish inconsistencies among the results that can be derived from it.

*** From S. Hawking, "Theoretical Advances in General Relativity," Einstein CENTENNIAL SYMPOSIUM, Harry Woolf (editor), Addison-Wesley, 1980. Reprinted by permission of Addison-Wesley.*





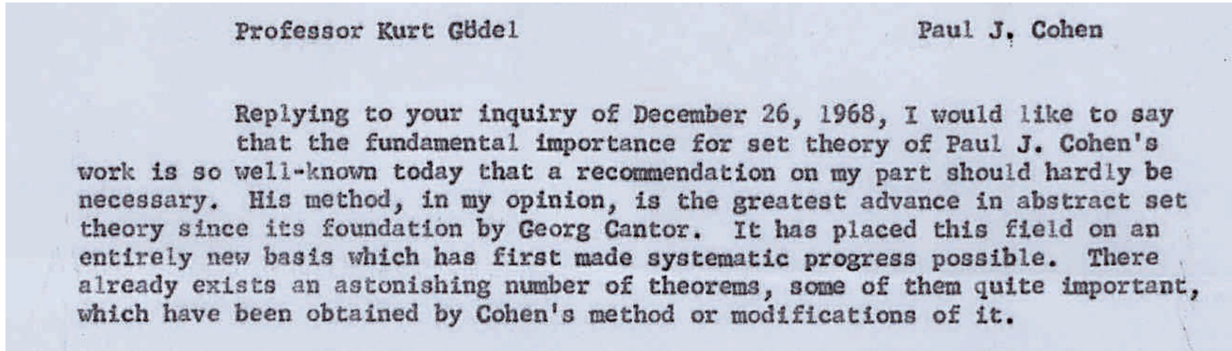


PHOTOS HERMAN LANDSHOFF/INSTITUTE FOR ADVANCED STUDY

In addition to being the town's most well-known intellectual, Einstein was one of Princeton's most beloved inhabitants. Local residents had many cherished encounters with Einstein as he walked through town. The far left image, Plate 4 in the portfolio, was chosen to be the basis for a commemorative stamp issued by the United States Postal Service in 1979 in conjunction with the Einstein Centennial. Einstein served on the Faculty of the Institute until 1946, continuing as a Professor Emeritus until his death in 1955. His presence at the Institute brought many distinguished visitors to Princeton, and his home was often graced by figures from the worlds of politics, entertainment, journalism, art, and science.

along the way. The so-called Riemann hypothesis, for example, has withstood the attack of generations of mathematicians ever since 1900 (or earlier). But the effort to solve it has led to some beautiful mathematics. Hilbert's fifth problem turned out to assert something that couldn't be true, though with fine tuning the "right" question—that is, the question Hilbert should have asked—was both formulated and solved. There is certainly an art to asking a good question in mathematics.

The problem known as the continuum hypothesis has had perhaps the strangest fate of all. The very first problem on the list, it is simple to state: how many points on a line are there? Strangely enough, this simple question turns out to be deeply intertwined with most of the interesting open problems in set theory, a field of mathematics with a very general focus, so general that all other mathematics can be seen as part of it, a kind of foundation on which the house of mathematics rests. Most objects in mathematics are infinite, and set theory is indeed just a theory of the infinite.


Professor Kurt Gödel   Paul J. Cohen

Replying to your inquiry of December 26, 1968, I would like to say that the fundamental importance for set theory of Paul J. Cohen's work is so well-known today that a recommendation on my part should hardly be necessary. His method, in my opinion, is the greatest advance in abstract set theory since its foundation by Georg Cantor. It has placed this field on an entirely new basis which has first made systematic progress possible. There already exists an astonishing number of theorems, some of them quite important, which have been obtained by Cohen's method or modifications of it.

PRINCETON UNIVERSITY

Kurt Gödel welcomed news that Paul Cohen had proved the unsolvability of the continuum hypothesis and supported his work enthusiastically, as in the above letter, dated January 16, 1969, recommending Cohen for a Guggenheim Fellowship.

What a State Mathematics Would Be In Today . . .

Before coming to the Institute where he was appointed as one of its first Professors in 1933, John von Neumann was a student of David Hilbert's in Göttingen. Von Neumann worked on Hilbert's program to find a complete and consistent set of axioms for all of mathematics. In addition to his many other contributions to mathematics and physics, von Neumann defined Hilbert space (unbounded operators on an infinite dimensional space), which he used to formulate a mathematical structure of quantum mechanics. Below, the late Herman Goldstine, a former Member in the Schools of Mathematics, Natural Sciences, and Historical Studies, recalls von Neumann's working dreams about Kurt Gödel's incompleteness theorem(s). (Excerpted from an oral history transcript available at www.princeton.edu/%7Emudd/finding_aids/mathoral/pmc15.htm; more information about von Neumann and Gödel is available at www.ias.edu/people/noted-figures.)

His work habits were very methodical. He would get up in the morning, and go to the Nassau Club to have breakfast. And then from the Nassau Club he'd come to the Institute around nine, nine-thirty, work until lunch, have lunch, and then work until, say, five, and then go on home. Many evenings he would entertain. Usually a few of us, maybe my wife and me. We would just sit around, and he might not even sit in the same room. He had a little study that opened off of the living room, and he would just sit in there sometimes. He would listen, and if something interested him, he would interrupt. Otherwise he would work away.

At night he would go to bed at a reasonable hour, and he would waken, I think, almost every night, judging from the things he told me and the few times that he and I shared hotel rooms. He would waken in the night, two, three in the morning, and would have thought through what he had been working on. He would then write. He would write down the things he had worked on.…

He, under Hilbert's tutelage, was trying to prove the opposite of the Gödel theorem. He worked and worked and worked at this, and one night he dreamed the proof. He got up and wrote it down, and he got very close to the end. He went and worked all day on that part, and the next night he dreamed again. He dreamed how to close the gap, and he got up and wrote, and he got within epsilon of the end, but he couldn't make the final step. So he went to bed. The next day he worked and worked and worked at it, and he said to me, "You know, it was very lucky, Herman, that I didn't dream the third night, or think what a state mathematics would be in today." [Laughter.]

How ironic then that the continuum hypothesis is unsolvable—indeed, "provably unsolvable," as we say. This means that none of the known mathematical methods—those that mathematicians actually use and find legitimate—will suffice to settle the continuum hypothesis one way or another. It seems odd that being unsolvable is the kind of thing one can prove about a mathematical question. In fact, there are many questions of this type, particularly about sets of real numbers—or sets of points on a line, if you like—that we know cannot be settled using standard mathematical methods.

Now, mathematics is not frozen in time or method—to the contrary, it is a very dynamic enterprise, each generation expanding and building on what went before. This process of expansion has not always been easy; sometimes it takes a while before new methods are accepted. This was true of set theory in the late nineteenth century. Its inventor, Georg Cantor, met with serious opposition on the part of those who were hesitant to admit infinite objects into mathematics.

What concerns us here is not so much the prehistory of the continuum hypothesis, but the present state of it, and the remarkable fact that mathematicians are in the midst of developing new methods by which the continuum hypothesis could be solved after all.

I will explain some of these developments, along with some of the more recent history of the continuum hypothesis, from the point of view of Kurt Gödel's role in them. Gödel, a Member of the Institute's School of Mathematics on several occasions in the 1930s, and then continuously from 1940 until 1976,[1] was a relative newcomer to the problem. But it turns out that Gödel's hand is visible in virtually every aspect of the problem, from the post-Cantorian period onward. Curiously enough, this is even more true now than it was at the time of Gödel's death nearly thirty-five years ago.

WHAT IS THE CONTINUUM HYPOTHESIS?

Mathematics is nowadays saturated with infinity. There are infinitely many positive whole numbers 0, 1, 2, 3 …. There are infinitely many lines, squares, circles in the plane, balls, cubes, polyhedra in the space, and so on. But there are also different *degrees* of infinity. Let us say that a set—a collection of mathematical objects such as numbers or lines—is *countable* if it has the same number of elements as the sequence of positive whole numbers 1, 2, 3 …. The set of positive whole numbers is thus countable, and so is the set of all rational numbers. In the early 1870s, Cantor made a momentous discovery: the set of real numbers (such as 5, 17, 5/12, $\sqrt{2}$, π, e,…) sometimes called the "continuum," is *uncountable*. By uncountable, we mean that if we try to count the points on a line one by one, we will never succeed, even if we use all of the whole numbers. Now it is natural to ask the following question: are there any infinities between the two infinities of whole numbers and of real numbers?

This is the continuum hypothesis, which proposes that if you are given a line with an infinite set of points marked out on it, then just two things can happen: either the set is countable, or it has as many elements as the whole line. There is no third infinity between the two.

At first, Cantor thought he had a proof of the continuum hypothesis; then he thought he could prove it was false; and then he gave up. This was a blow to Cantor, who saw this as a defect in his work—if one cannot answer such a simple question as the continuum hypothesis, how can one possibly go forward?

SOME HISTORY

The continuum hypothesis went on to become a very important problem, so much so that in 1900 Hilbert listed it as the first on his list of open problems, as previously mentioned. Hilbert eventually gave a proof of it in 1925—the proof was wrong, though it contained some important ideas.

Around the turn of the century, mathematicians were able to prove that the continuum hypothesis holds for a special class of sets called the Borel sets.[2] This is a concrete class of sets, containing, for the most part, the usual sets that mathematicians work with. Even with this early success in the special case of Borel sets though, and in spite of Hilbert's attempted solution, mathematicians began to speculate that the continuum hypothesis was in general not solvable at all. Hilbert, for whom nothing less than "the glory of human existence" seemed to depend upon the ability to resolve all such questions, was an exception. "*Wir müssen wissen. Wir werden wissen*,"[3] he said in 1930 in Königsberg. In a great irony of history, at the very same meeting, but on the day before, the young Gödel announced his first incompleteness theorem. This theorem, together with Gödel's second incompleteness theorem, is generally thought to have dealt a death blow to Hilbert's idea that every mathematical question that permits an exact formulation can be solved. Hilbert was not in the room at the time.

Gödel, however, became a strong advocate of the solvability of the continuum hypothesis, taking the view that his incompleteness theorems, though they show that some provably undecidable statements do exist, have nothing to do with whether the continuum hypothesis is solvable or not. Like Hilbert, Gödel maintained that the continuum hypothesis will be solved.

WHAT IS PROVABLE UNSOLVABILITY ANYWAY?

We arrive at an apparent conundrum. On the one hand, the continuum hypothesis is provably unsolvable, and on the other hand, both Gödel and Hilbert thought it was solvable. How to resolve this difficulty? What does it mean for something to be provably unsolvable anyway?

Some mathematical problems may be extremely difficult and therefore without a solution up to now, but one day someone may come up with a brilliant solution. Fermat's last theorem, for example, went unsolved for three and a half centuries. But then Andrew Wiles was able to solve it in 1994. The continuum hypothesis is a problem of a very different kind; we actually can prove that it is impossible to solve it using *current methods*, which is not a completely unknown phenomenon in mathematics. For

1 Appointed to the permanent Faculty in 1953

2 This was extended to the so-called analytic sets by Mikhail Suslin in 1917. Borel sets are named for Emile Borel, uncle of the late mathematician (and IAS Faculty member) Armand Borel.

3 "We must know. We will know."

example, the age-old trisection problem asks: can we trisect a given angle by using just a ruler and compass? The Greeks of the classical period were very puzzled by how to make such a trisection, and no wonder, for in the nineteenth century it was proved that it is impossible—not just very difficult but impossible. You need a little more than a ruler and compass to trisect an arbitrary angle—for example, a compass and a ruler with two marks on it.

It is the same with the continuum hypothesis: we know that it is impossible to solve using the tools we have in set theory at the moment. And up until recently nobody knew what the analogue of a ruler with two marks on it would be in this case. Since the current tools of set theory are so incredibly powerful that they cover all of existing mathematics, it is almost a philosophical question: what would it be like to go beyond set-theoretic methods and suggest something new? Still, this is exactly what is needed to solve the continuum hypothesis.

Juliette Kennedy is Associate Professor in the Department of Mathematics and Statistics at the University of Helsinki and a Member (2011–12) in the School of Historical Studies. In the history and foundations of mathematics, she has worked extensively on a project that attempts to put Kurt Gödel in full perspective, historically and foundationally. Her project at the Institute this year is centered on Gödel's notion of semantic content. The mathematical aspect of the project involves the question of how many of the larger "large cardinals" can be captured with a newly discovered class of L-like inner models of set theory.

CONSISTENCY

Gödel began to think about the continuum problem in the summer of 1930, though it wasn't until 1937 that Gödel proved the continuum hypothesis is at least *consistent*. This means that with current mathematical methods, we cannot prove that the continuum hypothesis is *false*.

Describing Gödel's solution would draw us into unneeded technicalities, but we can say a little bit about it. Gödel built a model of mathematics in which the continuum hypothesis is true. What is a model? This is something mathematicians build with the purpose of showing that something is possible, even if we admit that the model is just what it is, a kind of artificial construction. Children build model airplanes; architects draw up architectural plans; mathematicians build models of the mathematical universe. There is an important difference though, between mathematicians' models and architectural plans or model airplanes: building a model that has the exact property the mathematician has in mind, is, in all but trivial cases, extremely difficult. It is like a very great feat of engineering.

The idea behind Gödel's model, which we now call the *universe of constructible sets*, was that it should be made as small as is conceivably possible by throwing everything out that was not absolutely essential. It was a tour de force to show that what was left was enough to satisfy the requirements of mathematics, and, in addition, the continuum hypothesis. This did not show that the continuum hypothesis is really true, only that it is consistent, because Gödel's universe of constructible sets is not the real universe, only a kind of artifact. Still, it suffices to demonstrate the consistency of the continuum hypothesis.

UNSOLVABILITY

After Gödel's achievement, mathematicians sought a model in which the continuum hypothesis fails, just as Gödel found a model in which the continuum hypothesis holds. This would mean that the continuum hypothesis is unsolvable using current methods. If, on the one hand, one can build a picture of the mathematical universe in which it is true, and, on the other hand, if one can also build another universe in which it is false, it would essentially tell you that no information about the continuum hypothesis is lurking in the standard machinery of mathematics.

So how to build a model for the failure of the continuum hypothesis? Since Gödel's universe was the only nontrivial universe that had been introduced, and, moreover, it was the smallest possible, mathematicians quickly realized that they had to find a way to extend Gödel's model, by carefully adding real numbers to it. This is hair-raisingly difficult. It is like adding a new card to a huge house of cards, or, more exactly, like adding a new point to a line that already is—in a sense—a continuum. Where do you find the space to slip in a few new real numbers?

Looking back at Paul Cohen's solution, a logician has to slap her forehead, not once, but a few times. His idea was that the real numbers one adds should have "no properties," as strange as this may sound; they should be "generic," as he called them. In particular, a *Cohen real*, as they came to be called, should avoid "saying anything" nontrivial about the model. How to make this idea mathematically precise? That was Paul Cohen's great invention: the *forcing* method, which is a way to add new reals to a model of the mathematical universe.

Even with this idea, serious obstacles now stood in the way of a full proof. For example, one has to prove an extremely delicate metamathematical theorem—as these are called—that even though forcing extends the universe to a bigger one, one can still talk about it in the first universe; in technical terms, one has to prove that forcing is *definable*. Moreover, to violate the continuum hypothesis, we have to add *a lot* of new points to the continuum, and what we believe is "a lot" may in the final stretch turn out to be not so many after all. This last problem—the technical term is *preserving cardinals*—was a very serious matter. Cohen later wrote of his sense of unease at that point, "given the rumors that had circulated that Gödel was unable to handle the CH."[4] Perhaps Cohen sensed, while on the brink of his great discovery, the almost physical presence of the one mathematician who had walked the very long way up to that very door, but was unable to open it.

Two weeks later, while vacationing with his family in the Midwest, Cohen suddenly remembered a lemma from topology (due to N. A. Shanin), and this was just what was needed to show that everything falls into place. The proof was now finished. It would have been an astounding achievement for any set theorist, but the fact that it was solved by someone from a completely different field—Paul Cohen was an analyst after all, not a set theorist—seemed beyond belief.

WRITING THE PAPER

The story of what happened in the immediate aftermath of Cohen's announcement of his proof is very interesting, also from the point of view of human interest, so we will permit ourselves a slight digression in order to touch upon it here.

The announcement seems to have been made at a time when the extent of what had been shown was not clear, and the proof, though it was finished in all the essentials, was not in all details completely finished. In a first letter to Gödel, dated April 24, 1963, Cohen communicated his results. But about a week later, he wrote a second, more urgent letter, in which he expressed his fear that there might be a hidden flaw in the proof, and, at the same time, his exasperation with logicians, who could not believe that he was able to prove that very delicate theorem on the definability of forcing.

Cohen confessed in the letter that the situation was wearing, also considering "the unexpected interest my work has aroused among the general (non-logical) mathematical world."

Gödel replied with a very friendly letter, inviting Cohen to visit him, either at his home on Linden Lane or in his office at the Institute, writing, "You have just achieved the most important progress in set theory since its axiomatization. So you have every reason to be in high spirits."

Soon after receiving the letter, Cohen visited Gödel at home, whereupon Gödel checked the proof, and pronounced it correct.

4 P. J. Cohen, "The Discovery of Forcing"

Some Mathematical Details

Intuitively, the set-theoretic universe is the result of iterating basic constructions such as products $\prod_{i\in I} A_i$, unions $\bigcup_{i\in I} A_i$, and power sets $\mathcal{P}(A)$. In addition, the universe is assumed to satisfy so-called *reflection*: any property that it has is already possessed by some smaller universe, the domain of which is a set. The process starts from some given *urelements*, objects that are not sets, i.e., do not consist of elements, but it has been proven that the urelements are unnecessary and the process can be started from the empty set. Iterating this process into the transfinite, we obtain the *cumulative hierarchy* V of sets. Transfinite iterations are governed by *ordinals*, canonical representatives of well-ordered total orders, denoted by lower-case Greek letters α, β, etc. The hierarchy V is defined recursively by $V_\alpha = \bigcup_{\beta<\alpha} \mathcal{P}(V_\beta)$. The fact that $V = \bigcup_\alpha V_\alpha$ is the entire universe of sets is the intuitive content of the axioms of Zermelo-Frankel set theory with the Axiom of Choice, or ZFC, the basic system we have been working with all along.

Now Gödel's model of the ZFC axioms, the constructible hierarchy $L = \bigcup_\alpha L_\alpha$, where $L_\alpha = \bigcup_{\beta<\alpha} \mathcal{P}^L(V_\beta)$, is built up not by means of the unrestricted power set operation $\mathcal{P}(A)$, but by the restricted operation $\mathcal{P}^L(A)$, which takes from $\mathcal{P}(A)$ only those sets that are definable in $(A, \in)$. Gödel showed that we can consistently assume $V = L$, but Cohen showed that it is consistent to assume that there are real numbers that are not in L.

The Borel sets of reals are obtained from open sets by means of iterating complements and countable unions. If we enlarge the set of Borel sets by including images of continuous functions, we obtain the analytic sets; a set is coanalytic if its complement is analytic.

Finally, the projective sets are obtained from analytic sets by iterating complements and continuous images. The field of descriptive set theory asks, among other questions, whether the classical theory of analytic and coanalytic sets can be extended to the projective sets; in particular, whether the projective sets are Lebesgue measurable, and have the perfect set property and the property of Baire. This was settled in the 1980s with the work of Shelah and Woodin, building on earlier work of Solovay, who showed that the projective sets have these three properties as a consequence of the existence of certain so-called large cardinals. This also follows from *projective determinacy*, a principle that was shown by Martin and Steel to follow from the existence of such large cardinals. A cardinal α is called a large cardinal if V_α behaves in certain ways like V itself. For example, in that case, V_α is a model of ZFC, but more is assumed. A famous large cardinal is a *measurable* cardinal, introduced by Stanislaw Ulam, an example of which is the smallest cardinal that admits a nontrivial countably additive two-valued measure.

What followed over the next six months is a voluminous correspondence between the two, centered around the writing of the paper for the *Proceedings of the National Academy of Sciences*. The paper had to be carefully written; but Cohen was clearly impatient to go on to other work. It therefore fell to Gödel to fine tune the argument, as well as simplify it, all the while keeping Cohen in good spirits. The Gödel that emerges in these letters—sovereign, generous, and full of avuncular goodwill, will be unfamiliar to readers of the biographies—especially if one keeps in mind that by 1963 Gödel had devoted a good part of twenty-five years to solving the continuum problem himself, without success. "Your proof is the very best possible," Gödel wrote at one point. "Reading it is like reading a really good play."

(Continued on page 13)

Robbert Dijkgraaf …

… was born in Ridderkerk in the Netherlands in 1960. He earned a B.Sc. (1982), an M.Sc. (1986), and a Ph.D. (1989) in theoretical physics from Utrecht University, where his adviser was Gerard 't Hooft, the 1999 Nobel Prize Laureate in Physics and a frequent visitor since the 1970s to the Institute's School of Natural Sciences.

… was elected President of the Royal Netherlands Academy of Arts and Sciences (KNAW) in 2008. The Academy, founded in 1808 as an advisory body to the Dutch government, promotes quality in science and scholarship and strives to ensure that Dutch scholars and scientists contribute to cultural, social, and economic progress. It is also responsible for eighteen national research institutes.

Robbert Dijkgraaf used his Spinoza Prize grant to conceive and launch a science website for children, Proefjes.nl.

… studied painting at the Gerrit Rietveld Academy in Amsterdam in 1982–84, was a Research Associate in the Physics Department at Princeton University from 1989–91, and then was a Member in the School of Natural Sciences at the Institute from 1991–92. He served as Professor of Mathematical Physics at the Korteweg-de Vries Institute for Mathematics at the University of Amsterdam from 1992–2004. He will continue as Distinguished University Professor at the University of Amsterdam, a position he has held since 2005, after becoming Director of the Institute.

… was awarded the Spinoza Prize, the highest scientific award in the Netherlands, in 2003, and the Physica Prize of the Dutch Physical Society in 2002.

… is an active proponent of the sciences who frequently appears on Dutch national television and has a monthly column in the Dutch newspaper *NRC Handelsblad*. He used his Spinoza Prize grant to conceive and launch a website for children, Proefjes.nl, in an effort to cultivate and sustain understanding and involvement in the sciences.

… serves as the Co-Chair of the InterAcademy Council, the research council of the science academies of the world, which provides reporting and advisement on global scientific, technological, and health issues to governments and international organizations, and recently reviewed the management and procedures of the Intergovernmental Panel on Climate Change at the request of the United Nations Secretary-General.

… and his wife, author Pia de Jong, have three children. De Jong's critically acclaimed 2008 debut novel, *Lange Dagen* (*Long Days*), received the 2008 Golden Owl Literature Readers Prize, and established de Jong as one of the leading voices in fiction in the Netherlands. Her most recent novel, *Dieptevrees* (*Depth Fear*), published in 2010, has been widely praised by the press for its strong, elegant prose. She writes a weekly column in the newspaper *Het Financieele Dagblad*.

… will be the ninth Director of the Institute, following Abraham Flexner (1930–39), Frank Aydelotte (1939–1947), J. Robert Oppenheimer (1947–66), Carl Kaysen (1966–76), Harry Woolf (1976–87), Marvin L. Goldberger (1987–91), Phillip A. Griffiths (1991–2003), and Peter Goddard (2004–).

More information about Dijkgraaf's appointment may be found online at www.ias.edu/news/press-releases/2011/11/14/dijkgraaf-appt. A video of Dijkgraaf speaking about the mysteries of the universe at a TEDx event in 2009 may be viewed at http://tedxtalks.ted.com/video/TEDxAmsterdam-Robbert-Dijkgraaf.

I see in Robbert Dijkgraaf a dynamic, creative, and forward-looking scientist who understands intimately the mission of the Institute, has a strong commitment to the universal quest for knowledge that the Institute stands for, and has the passion to inspire scholars in all fields. He combines administrative experience with science research at the highest levels, and I am fully confident that under his directorship the Institute will continue to thrive in every way. *—Nicola Di Cosmo, Henry Luce Professor in East Asian Studies, School of Historical Studies*

Robbert Dijkgraaf is an international public intellectual. Our second Director recruited from abroad, he exemplifies the international nature of the Institute for Advanced Study. I think he will be very effective in elucidating the mission of the Institute to the public, and also in advocating the case for scholarship in general as a valuable activity. *—Robert MacPherson, Hermann Weyl Professor, School of Mathematics*

Robbert Dijkgraaf is a terrific appointment for the IAS. He's a top scientist with broad humanistic training and experience who knows the Institute well and admires its best aspects. He'll be an outstanding leader for the Faculty and an advocate for the Institute nationally and internationally. *—Joan Wallach Scott, Harold F. Linder Professor, School of Social Science*

Robbert Dijkgraaf is a mathematical physicist of great distinction. He has made many outstanding contributions to our understanding of quantum fields and strings and their relations to problems of gauge theory, geometry, and quantum black holes. Since his early years at the Institute when he and I collaborated, I have always looked forward to his papers. He is a leader in both science and public policy, and it will be great to have him leading the Institute. *—Edward Witten, Charles Simonyi Professor, School of Natural Sciences*

Robbert Dijkgraaf's distinguished achievements as a scientist, administrator, communicator, and advocate for science and the arts make him an absolutely outstanding choice for Director of the IAS. I am certain that the Institute will flourish under his leadership. *—Peter Goddard, Director of the Institute*

Robbert Dijkgraaf is a marvelous scientist and talented administrator with a global perspective that will serve the Institute well. The Institute and wider Princeton communities will be enriched by Dijkgraaf's charismatic presence and broad interests. He is a superb choice to lead the Institute. *—Phillip A. Griffiths, Professor Emeritus, School of Mathematics, and former Director of the Institute (1991–2003)*

Robbert Dijkgraaf is a brilliant choice for the IAS directorship. In addition to being a leading theoretical and mathematical physicist, he is a scientific statesman with worldwide recognition. I have known him for twenty-five years, and I can add that he is a wonderfully warm and cultured individual, ideally suited to lead an institution with the IAS's broad scholarly mandate. We are incredibly fortunate to have been able to recruit him. *—Curtis Callan, Institute Trustee and James S. McDonnell Distinguished University Professor of Physics and Chair, Department of Physics, Princeton University*

We live in a world in which the impact and influence of science knows no boundaries, nor should they. Testament to this fact is the selection of Robbert Dijkgraaf as the new Director of the Institute. His appointment reflects the international nature of science and knowledge in our increasingly complex and interconnected global community. His rigorous intellect, matchless talent as a scientist, thinker, and teacher, along with the depth and breadth of his experience as an institutional administrator, make him an outstanding choice to lead the Institute. We are delighted that Dijkgraaf's appointment comes with the unanimous and enthusiastic endorsement of the Search Committee and the Board. *—Vartan Gregorian, Institute Trustee, Chair of the Search Committee, and President of Carnegie Corporation of New York*

The continued leading role of the Institute for Advanced Study in increasing the knowledge of humanity is assured with the appointment of Dr. Robbert Dijkgraaf as Director. Dr. Dijkgraaf's distinguished contributions in the fields of mathematical physics and string theory are matched by his inspiring passion for communicating the critical value of science to society. With Dr. Dijkgraaf's appointment, it is clear that the Institute will continue its tradition of achieving breakthroughs in curiosity-based research under the guidance of one of the world's great thought leaders. *—John S. Hendricks, Institute Trustee and Founder and Chairman of Discovery Communications*

The IAS is an exceptional institution with a unique research and mentoring mission. As our Trustee Vartan Gregorian once put it, the IAS is the "university to universities." The Director's role calls for an individual who has made truly great contributions to his or her field of specialization and who also has broad interests that span the full spectrum of activities pursued at IAS. We are indeed fortunate to have such an outstanding, multifaceted scholar as Robbert Dijkgraaf joining us as Director in July 2012. *—Martin L. Leibowitz, Vice Chairman of the Institute's Board of Trustees, President of the Corporation, and Managing Director of Morgan Stanley*

Robbert Dijkgraaf is an outstanding theoretical physicist, a respected ambassador for science and education, and a wise and influential contributor to public policy. His distinction, experience, and personality render him ideally qualified to lead the Institute into an era of even wider international excellence." *—Martin Rees, Institute Trustee and Astronomer Royal and Master of Trinity College, University of Cambridge*

Professor Dijkgraaf is an extraordinary figure with an international reputation as a physicist, as a thought leader in science policy, and in the distinguished leadership of scientific institutions. His leadership of the Netherlands Royal Academy of Arts and Sciences and his ability to effectively mobilize the heads of the National Academies around the world through the InterAcademy Council have demonstrated his ability to bring together scholars from a wide variety of disciplines to deal effectively with important scientific and critical public policy issues. He is a worthy successor to Peter Goddard, who has provided such memorable leadership to the Institute over the last decade. He is sure to play a distinguished role in enhancing the work of the Institute. Finally, it will be a special pleasure to welcome his family to the Princeton community. *—Harold T. Shapiro, Institute Trustee and President Emeritus and Professor of Economics and Public Affairs, Princeton University*

I can't imagine a person more fit to lead the Institute for Advanced Study than Robbert Dijkgraaf. He is both an outstanding physicist and an excellent leader with a broad interest in public awareness of science. The appointment will have a positive impact both on the Institute and on the nation at large. *—James H. Simons, Vice Chairman of the Institute's Board of Trustees, Chairman of the Board of Renaissance Technologies LLC, and President of Euclidean Capital LLC*

The Board of Trustees is honored and delighted that Dr. Dijkgraaf has accepted our invitation to join as the next Director of the Institute. This is a great moment not only for the Institute and its Faculty but also for the international community of scholars who take part in the curiosity-driven research pursued at IAS. We look forward to the continuation of the brilliant tradition of directorships since the founding of the Institute in 1930. *—Charles Simonyi, Chairman of the Institute's Board of Trustees and Chairman and Chief Technology Officer of Intentional Software Corporation*

Robbert Dijkgraaf joins a long line of distinguished scholars who have worked at the Institute, including such luminaries as Albert Einstein, John von Neumann, and Robert Oppenheimer. He brings a reputation not only as a premier research scientist and administrator but also as a dedicated advocate of fostering and promoting a greater public awareness of science. *—Shelby White, Institute Trustee and Trustee of the Leon Levy Foundation*

I am enormously pleased that Robbert has been selected as the next Director of the Institute for Advanced Study. He has demonstrated great leadership in his present roles as President of the Royal Netherlands Academy of Arts and Sciences and as Co-Chair of the InterAcademy Council of the world's science academies. Importantly, Robbert is not only an outstanding theoretical physicist, but also a charismatic and idealistic human being. He has set a wonderful example for other scientists by dedicating a large amount of effort to communicating science to the public and to cultivating the next generation of scientists through science education at all levels. Hopefully, his new position will enable him to reach an even wider audience around the world. *—Bruce Alberts, Editor-in-Chief of* Science *magazine and President Emeritus of the National Academy of Sciences*

Robbert Dijkgraaf is a world-class scientist who brings mathematical rigor, great energy, and humanity to every one of his many activities. He is greatly admired for his own original research and for his contributions to science education. Simultaneously, he is a great leader of organizations who displays genuine interest in learning what other people are doing. *—Ralph J. Cicerone, President of the National Academy of Sciences*

An accomplished physicist and an inspiring scientific statesman, Robbert Dijkgraaf is a magnificent choice as Director of the IAS. *—David Gross, Member (1973–74, 1977–78) in the School of Natural Sciences and Director and holder of the Frederick W. Gluck Chair in Theoretical Physics, Kalvi Institute for Theoretical Physics*

Robbert Dijkgraaf is an inspired choice for Director of IAS. His research in physics, his ability to explain science to others, his broad interests, and his personal presence ensure his effective leadership as Director of IAS. *—Isadore Singer, Member (1955–56, 1975–76) in the School of Mathematics and Emeritus Institute Professor, Massachusetts Institute of Technology*

DIJKGRAAF *(Continued from page 1)*

with Witten and fellow Dutch graduate students Erik and Herman Verlinde, who were based at the Institute and the University, respectively. At that time, a sizeable fraction of the string theory community was concentrated in the Princeton area, so there was a tremendous sense of collective excitement. My own research during these years was directed at matrix models and black holes, two topics that I have continued working on ever since.

Looking back, the Institute years clearly set the course for my career, both in terms of research topics and contacts. This formative period also made me, as a physicist, appreciate the power and attractiveness of mathematics. I only fully realized how perfect the working circumstances were when I became a professor of mathematical physics at the University of Amsterdam and was confronted with days loaded with teaching classes, supervising students, and endless committee meetings.

My family and I visited the Institute again for a long stay in 2002. At that time, I really needed to revitalize my research. The work I did at the Institute laid the foundations for my subsequent work on matrix models and supersymmetric gauge theories with my long-time collaborator Cumrun Vafa of Harvard University. My children were very young at the time and mostly remember that we made a hedgehog from a snowball and twigs, which we kept for days in the freezer.

As a physicist, it is exciting to be a part of an international community of scientists who share their enthusiasm for finding out how the universe works. It is remarkable that physics allows you to capture deep physical principles in terms of elegant mathematics. Sometimes it seems as if we can have truth and beauty at the same time, as the Institute seal claims.

My first introduction to modern physics was an issue of *Scientific American* on quarks that I read in high school. However, the most exciting part of this article was not so much the physics, which might have been a bit over my head, but the fact that a single paper could be written by a team of scientists from various countries. I was amazed to see that elementary particles could bring people from different parts of the globe together.

Einstein pointed out that the most remarkable fact about the universe is that it can be understood at all. We have not yet met signs that read "forbidden for humans." The challenge of making sense of the enormous diversity of facts, structures, ideas, and cultures around us motivates me every day. There will be progress in science, but where and how is always a surprise.

When I studied painting at the Rietveld Academy of Fine Arts, it reminded me how important and satisfying it is to produce original work, preferably every day. Research is the common denominator of art and science. However, as a scientist it is easier to add to the work of others. There is vicarious pleasure in seeing your colleagues obtain exciting results, since it triggers new thoughts and research projects. If science is a work of art, it is definitely a collective one. The artist on the other hand is fortunate that he or she can avoid the painful collision with reality that a scientist sometimes has to experience. Nature has her own ideas about what makes good science.

The word "scientist" is a comparatively late, nineteenth-century invention that sometimes unnecessarily complicates our life. The natural sciences and the humanities have much more in common than is often realized. Critical Renaissance scholarship of texts, especially religious ones, was crucial in starting the modern scientific revolution. In fact, in Dutch we use the convenient single word "*wetenschap*" to encompass the humanities, social sciences, and natural sciences. With my background in physics and mathematics, I look forward to building more bridges to the humanities and social sciences, as I have done at the Royal Netherlands Academy.

Sharing my own excitement and wonder has always been an important aspect of my research. Even as a young child, I could only really enjoy an experience—be it a book, movie, or holiday—if I could share it with my friends. It is a remarkable phenomenon that explaining your research, even to a general audience, can give you so many new ideas. I feel we should dedicate some of the creativity required in our research to exploring new ways of reaching out to the general public, in particular to younger generations. Only by capitalizing on all available talent, from all over the world, can we make sure that we reach the highest level of understanding. Of course, it would be wonderful to see some of that talent come to the Institute! ■

Robbert Dijkgraaf's academic work has been on the mathematical physics of quantum fields and strings, and their interplay with gravity, geometry, and elementary particles. Among other things, Dijkgraaf's work has greatly influenced our understanding of string theory in low dimensions, topological strings and their relations to invariants studied by geometers, the dynamics of supersymmetric gauge theories in the strongly coupled regime, and the use of methods of string theory and/or gauge theory to understand the quantum states of black holes. His widely cited works cover an extensive range of topics.

In a broad sense, a primary theme in Dijkgraaf's work has been the recognition of ideas in pure geometry that can be usefully applied to mathematical physics, and vice-versa. For example, he has related quantum states of black holes to automorphic forms in unexpected ways. On other occasions, Dijkgraaf has found powerful applications of ideas in one area of mathematical physics that originated in another area. For instance, a recurrent theme in his work has been the use of models of random matrices, sometimes in connection with associated hierarchies of integrable differential equations, to gain new and often surprising information about a great variety of contemporary problems involving string theory and gauge theory. This particular theme well illustrates the relations of Dijkgraaf's area of research to many other fields. Random matrices, which were introduced in physics over half a century ago by Eugene Wigner, with early contributions by John von Neumann, Herman Goldstine, and Freeman Dyson, among others, have numerous applications in mathematics, science, and engineering.

In sum, Robbert Dijkgraaf has made exciting contributions to many rapidly developing areas of contemporary mathematical physics.

—Edward Witten, Charles Simonyi Professor in the School of Natural Sciences

CONTINUUM HYPOTHESIS *(Continued from page 11)*

Gödel and Cohen bequeathed to set theorists the only two model construction methods they have. Gödel's method shows how to "shrink" the set-theoretic universe to obtain a concrete and comprehensible structure. Cohen's method allows us to expand the set-theoretic universe in accordance with the intuition that the set of real numbers is very large. Building on this solid foundation, future generations of set theorists have been able to make spectacular advances.

There was one last episode concerning Gödel and the continuum hypothesis. In 1972, Gödel circulated a paper called "Some considerations leading to the probable conclusion that the true power of the continuum is $\aleph_2$," which derived the failure of the continuum hypothesis from some new assumptions, the so-called scale axioms of Hausdorff. The proof was incorrect, and Gödel withdrew it, blaming his illness. In 2000, Jörg Brendle, Paul Larson, and Stevo Todorcevic[5] isolated three principles implicit in Gödel's paper, which, taken together, put a bound on the size of the continuum. And subsequently Gödel's $\aleph_2$ became a candidate of choice for many set theorists, as various important new principles from conceptually quite different areas were shown to imply that the size of the continuum is $\aleph_2$.

THE FUTURE

Currently, there are two main programs in set theory. The *inner model program* seeks to construct models that resemble Gödel's universe of constructible sets, but such that certain strong principles, called large cardinal axioms, would hold in them. These are very powerful new principles, which go beyond current mathematical methods (axioms). As Gödel predicted with great prescience in the 1940s, such cardinals have now become indispensable in contemporary set theory. One way to certify their existence is to build a model of the universe for them—not just any model, but one that resembles Gödel's constructible universe, which has by now become what is called "canonical." In fact, this may be the single most important question in set theory at the moment—whether the universe is "like" Gödel's universe, or whether it is very far from it. If this question is answered, in particular if the *inner model program* succeeds, the continuum hypothesis will be solved.

The other program has to do with fixing larger and larger parts of the mathematical universe, beyond the world of the previously mentioned Borel sets. Here also, if the program succeeds, the continuum hypothesis will be solved.

We end with the work of another seminal figure, Saharon Shelah. Shelah has solved a generalized form of the continuum hypothesis, in the following sense: perhaps Hilbert was asking the wrong question! The right question, according to Shelah, is perhaps not how many points are on a line, but rather how many "small" subsets of a given set you need to cover every small subset by only a few of them. In a series of spectacular results using this idea in his so-called pcf-theory, Shelah was able to reverse a trend of fifty years of independence results in cardinal arithmetic, by obtaining provable bounds on the exponential function. The most dramatic of these is $2^{\aleph_\omega} \leq 2^{\aleph_0} + \aleph_{\omega 4}$. Strictly speaking, this does not bear on the continuum hypothesis directly, since Shelah changed the question and also because the result is about bigger sets. But it is a remarkable result in the general direction of the continuum hypothesis.

In his paper,[6] Shelah quotes Andrew Gleason, who made a major contribution to the solution of Hilbert's fifth problem:

> *Of course, many mathematicians are not aware that the problem as stated by Hilbert is not the problem that has been ultimately called the Fifth Problem. It was shown very, very early that what he was asking people to consider was actually false. He asked to show that the action of a locally-euclidean group on a manifold was always analytic, and that's false . . . you had to change things considerably before you could make the statement he was concerned with true. That's sort of interesting, I think. It's also part of the way a mathematical theory develops. People have ideas about what ought to be so and they propose this as a good question to work on, and then it turns out that part of it isn't so.*

So maybe the continuum problem has been solved after all, and we just haven't realized it yet. ■

5 In their "Rectangular Axioms, Perfect Set Properties and Decomposition"

6 "The Generalized Continuum Hypothesis Revisited"

Carnegie Corporation and IAS: Transforming Science and Mathematics Education

Carnegie Corporation of New York is a generous supporter of the Institute for Advanced Study. Vartan Gregorian, its President and an Institute Trustee since 1987, often speaks of the Institute as "a university to universities," in recognition of its role as one of the world's leading centers for theoretical research and intellectual inquiry. Carnegie Corporation has supported the Institute's work in the humanities with a recent grant emphasizing collaboration and cross-fertilization between the Schools of Historical Studies and Social Science. It has also funded joint projects with the Institute that aim to have a transformative impact on science and mathematics education in the United States and Africa. Its support of these projects, the Opportunity Equation in the United States and the Regional Initiative in Science and Education (RISE) in Africa, totals more than $13 million since 2007.

ARLEN HASTINGS

Paul Mensah, a Ghanaian Ph.D. student in RISE's sub-Saharan Africa water resources network, conducts research at Rhodes University, South Africa, on the effects of run-off herbicide on the life cycle of the indigenous shrimp Caridina nilotica.

OPPORTUNITY EQUATION IN THE U.S.

The Opportunity Equation, a partnership between Carnegie Corporation of New York and the Institute, grew out of a report released in 2009 by the Carnegie-IAS Commission on Mathematics and Science Education, "The Opportunity Equation: Transforming Mathematics and Science Education for Citizenship and the Global Economy." This report presented Americans with a vision for excellent and equitable learning in science, technology, engineering, and mathematics (STEM) that would reach all students in the United States and prepare them for full participation as citizens and as workers in an increasingly global economy.

In the two years since its release, the Opportunity Equation report has served as a call to action, a unifying framework, and a mission statement. The Opportunity Equation has focused on advancing the report's comprehensive plan for transforming American STEM education through a variety of initiatives. This mobilization for excellence and equity is co-chaired by Phillip A. Griffiths, former Director of the Institute and Professor Emeritus in its School of Mathematics, and Michele Cahill, Vice President of National Programs at Carnegie Corporation of New York.

One recently launched initiative is the 100Kin10 project, a cross-sector movement of more than eighty partner organizations committed to preparing one hundred thousand new STEM teachers over the next ten years. "100Kin10 is possible, and our students deserve it," says Griffiths. "As we outlined in our 2009 Opportunity Equation report, we know how to recruit, train, and retain excellent STEM teachers. If this country's museums, schools, corporations, education organizations, and other potential partners come forward and commit to action, we will meet our goal."

The original report and an update may be found at www.opportunityequation.org/report. Information about 100Kin10 may be found at www.100Kin10.org.

RISE IN AFRICA

RISE is an ambitious program designed to prepare a new generation of scientists and engineers to teach, research, and innovate in Africa's universities. Consisting of five competitively selected, university-based research and training networks involving fourteen institutions in nine African countries, RISE is administered by the Institute's Science Initiative Group, which is also chaired by Griffiths.

Now in its fourth year, RISE has its roots in the Partnership for Higher Education in Africa (PHEA). PHEA, active from 2000–10, was a joint project of Carnegie Corporation of New York and six other U.S. foundations with a shared commitment to preparing Africa's next generation of academics. "We are all acutely aware of Africa's urgent need to adapt and apply science and technology to alleviate poverty and catalyze economic development," said Gregorian. "By generating a critical mass of promising, world-class scientists and deploying them to cultivate the fertile minds of students, Africa will be harnessing two resources, which it has in great abundance: innovation and determination."

More than a hundred students are currently supported by RISE, among them Justin Omolo, who uses advanced equipment at the University of Pretoria, South Africa, to isolate and synthesize anti-HIV compounds from a plant found in his native Tanzania; Nigerian student Adenike Olaseinde, whose research on the corrosion resistance of duplex stainless steel earned her a prestigious Women in Science prize from the South African government; and Pramod Chumun, from Mauritius, whose work at the Institute of Marine Sciences in Zanzibar focuses on the symbiotic relationship between corals and micro-algae, a key to the survival of coral reefs in the Indian Ocean.

Information about RISE may be found at www.ias.edu/rise. ■

Marilyn and James Simons Hall

KATHERINE BELYI

Avi Wigderson (right), Herbert H. Maass Professor in the School of Mathematics, and Menachem Magidor of the Hebrew University of Jerusalem leave Simons Hall.

In October, the Institute for Advanced Study's Dining Hall—a central fixture in the life of the Institute where scholars and scientists share meals and conversation—was dedicated as the Marilyn and James Simons Hall, in recognition of the Simonses' lead role in the donation of a $100 million unrestricted challenge grant from the Simons Foundation and the Charles and Lisa Simonyi Fund for Arts and Sciences.

The donation, which is the largest in real terms since the founders' gift establishing the Institute in 1930, is serving as the basis for a $200 million campaign to strengthen the Institute's endowment. The grant must be matched by funds from donors within the next four years; all funds received will be matched dollar for dollar by the Simons Foundation and the Simonyi Fund.

Carl Kaysen, the Institute's fourth Director, commissioned architect Robert Geddes—who, with his wife Evelyn, has been a Friend of the Institute since 1987—to build the Dining Hall and West Building in 1969. In the summary report that was published at the end of Kaysen's tenure in 1976, he describes the Dining Hall—now known as Simons Hall—as having "contributed a great deal towards enlarging and humanizing the nonacademic life of the Institute. New activities, to counter the tendency towards isolation felt by some Members, arise almost spontaneously in its setting. . . . All of these occasions are important in stimulating contact amongst Members of the several Schools. It is an end valuable in itself, and one that sometimes bears intellectual fruit." ■

GEARY *(Continued from page 3)*

philosophy from Spring Hill College in Alabama. He earned his M.Phil. in 1973 and his Ph.D. in 1974, both in medieval studies, from Yale University. He was named Assistant Professor at Princeton University beginning in 1974, and in 1980, he joined the faculty of the University of Florida as Associate Professor and was named Professor in 1986. Geary moved to the University of California, Los Angeles, in 1993, when he became Director of the UCLA Center for Medieval and Renaissance Studies. He held that position until 1998, and from 1996 to 1998, he was also the Director of the UCLA Humanities Consortium. Geary was Professor of History at UCLA from 1993 to 2004, at which time he was named Distinguished Professor of History. From 1998 to 2000, he was also Professor of History and Robert M. Conway Director of the Medieval Institute at the University of Notre Dame.

Geary was a Research Fellow at the Max Planck Institut für Geschichte in Göttingen in 1990 and a Fellow at the Hungarian Institute for Advanced Study in 2009. He served as President of the Medieval Academy of America from 2008–09 and is currently a Fellow. He is also a Corresponding Fellow of the British Academy and of the Austrian Academy of Sciences and is a Membre Associé Étranger of the Société Nationale des Antiquaires. He was named the first Lester K. Little Resident at the American Academy in Rome in 2006. In 2011, he was awarded the Alexander von Humboldt Foundation's Anneliese Maier Research Prize. He is Editor-in-Chief of the *International Encyclopedia for the Middle Ages—Online*, coeditor of the Oxford University Press series Oxford Studies in Medieval European History, and serves on the editorial advisory boards of several publications, including *Mumlus: Rivista di Didattica della Storia* and *Sredniye Veka*. He is also a member of the editorial board of *History and Memory*. ■

Donor-Supported Memberships Enable Curiosity-Driven Research

Donors to the Institute for Advanced Study may choose to direct their gifts in many ways, but among the most important are those gifts directed to the support of Memberships. Each year, some two hundred individuals from around the world come to the Institute to pursue their research without restriction. All Members—whether emerging scholars, scientists at the beginning of their careers, or established researchers—are selected on the basis of their outstanding achievements and promise. Securing funding to support Memberships is one of the Institute's highest priorities. Sufficient funding allows the Institute to be competitive with other research institutions while ensuring its continued independence and the conservation of its general endowment.

Memberships may be funded through gifts or grants of endowment or annual operating support, and depending on the level of support, donor generosity is recognized with a named Membership. Named Memberships are listed in the Institute's *Faculty and Members* booklet and in its annual report, as well as in publications and presentations made by the Members during their stay at the Institute.

The Institute will name a Membership in appreciation of a gift or grant of $1 million or more, given to establish an endowment for the purpose of supporting an existing Membership, either through an outright gift or a planned gift or bequest. In 2000, Bob and Ginny Loughlin, Friends of the Institute for Advanced Study, established a ten-year charitable remainder trust, which established an endowment to support two Members named in honor of Bob's father William D. Loughlin, one in the School of Historical Studies and one in the School of Natural Sciences. This year's William D. Loughlin Members are Annemarie Weyl Carr, University Distinguished Professor of Art History at Southern Methodist University, and Jonathan Heckman, a postdoctoral Member interested in both formal and phenomenological aspects of string theory, particle physics, and cosmology.

Securing funding to support Memberships is one of the Institute's highest priorities. Sufficient funding allows the Institute to be competitive with other research institutions while ensuring its continued independence and the conservation of its general endowment.

Gifts or grants of annual operating support designated for Member support are recognized with a named Membership beginning at $50,000 per year. This year, the Simons Center for Systems Biology named Jean-Claude Nicolas of the Université Pierre et Marie Curie the Susan and Jim Blair Member in Biology. Nicolas is focusing on LINE elements, which are selfish genes that move in the human genome to new locations over the lifetime of the host.

In addition, individual members of the Friends of the Institute for Advanced Study who contribute annually at the Founders' Circle level are able to name a Membership in the School of their choice. As an example, this year Vasileios Marinis, Assistant Professor of Christian Art and Architecture at Yale University, is the Louise and John Steffens Founders' Circle Member in the School of Historical Studies. He is investigating the intersection of architecture, ritual, and function in the Middle and Late Byzantine churches of Constantinople.

Two important groups collectively fund Memberships each year. Through their generous annual donations, the Friends of the Institute for Advanced Study fund four Members, one in each of the Institute's Schools. Similarly, the Association of Members of the Institute for Advanced Study (AMIAS) also funds a Member in each School, through a combination of endowment funds and annual gifts. AMIAS is the organization of scholars and researchers who are current or former Members or Visitors at the Institute. The central purpose of the group is to support the mission of the Institute and to continue for future generations opportunities for independent, curiosity-driven scholarship.

For more information about how to support Memberships at the Institute, please contact Michael Gehret, Associate Director, at mgehret@ias.edu or (609) 734-8218. ■

Artist-in-Residence Program Launches New Season of Concerts and Talks

EDWARD T. CONE CONCERT SERIES EXAMINES CLASSICAL MUSIC FROM UNUSUAL ANGLES

Now entering his third year as Institute Artist-in-Residence, Derek Bermel continues to entertain and enchant his audiences for the Edward T. Cone Concert Series. The 2011–12 season of "The Harmonic Series" offers both new experiences and the return of performers whose previous visits proved extremely popular.

"When organizing the performers and works for this season, I wanted to examine what classical music is when viewed from unusual angles," said Bermel. "In light of that, this season the 'Harmonic Series' will present four fresh and unique approaches to the classical tradition."

In the Composer Performs, the opening concerts in November, Bermel, on clarinet, teamed up with the young pianist and composer Timothy Andres as they presented their own works viewed through the prism of older compositions by Schumann, Ives, and Copland. The pair were accompanied by Harumi Rhodes on violin.

On December 2 and 3, Uri Caine and Mario Laginha, world-renowned jazz pianists and composers, reinterpreted baroque forms, including canon and fugue, at the border of composition and improvisation. On February 17 and 18, the Grammy Award–winning sextet eighth blackbird will return to the Institute with a collection of new works from young American and European composers.

Finally, on March 23 and 24, Music from Copland House, which performed at the Institute in 2003 and 2005, will return in an innovative collaboration with Music from China, featuring works written for hybrid ensembles of Western and Chinese instruments.

Bermel continues to organize a series of pre- and post-concert talks, providing discussions of the music on the program and related topics. They are held each Friday following the 8:00 p.m. performances and each Saturday at 6:30 p.m., preceding the concerts in Wolfensohn Hall.

For more details about the Artist-in-Residence program and the Edward T. Cone Concert Series, please visit www.ias.edu/air.

WRITERS CONVERSATIONS RETURN WITH STEPHEN SONDHEIM ON THE ART OF MUSICAL THEATER

"Art is hard work," Stephen Sondheim told members of the Institute community gathered in November for the latest in a series of Writers Conversations. Sondheim, the composer and lyricist whose works include *A Funny Thing Happened on the Way to the Forum*, *Company*, *Follies*, *A Little Night Music*, and *Sweeney Todd*, made his Broadway debut at age twenty-seven as the lyricist of *West Side Story*. "Everybody is talented in one way or another," Sondheim said. "It's the hard work, and the application of hard work, and learning the principles of how you make a piece of art out of your imagination, out of your vision."

Sondheim spoke in conversation with Derek Bermel, the Institute's Artist-in-Residence, who organizes the Writers Conversations series to engage the Institute community in discussions about the creative process. Past speakers have included Alex Ross, the music critic of the *New Yorker* magazine; artist Alex Katz and his son, writer Vincent Katz; video artist Shimon Attie; a panel of groundbreaking poets; and Steve Bodow, the Head Writer and Supervising Producer of *The Daily Show with Jon Stewart*.

In a wide-ranging conversation, Sondheim recalled serving as a "gofer" for Oscar Hammerstein at age seventeen, fetching coffee and typing scripts during the production of *Allegro*, a failed but innovative musical. Later, he was mentored in composition by Milton Babbitt, the late avant-garde composer and Professor at Princeton University, with whom Sondheim would meet weekly to analyze show tunes before moving on to Mozart's *Jupiter Symphony*. Sondheim also spoke of his new book, *Look, I Made a Hat: Collected Lyrics (1981–2011) with Attendant Comments, Amplifications, Dogmas, Harangues, Digressions, Anecdotes, and Miscellany* (Knopf, 2011), which—taking off from his first book of collected lyrics, *Finishing the Hat* (Knopf, 2010)—reproduces early sketches and drafts from his shows, along with commentary.

Though the books deal primarily with the process of lyric writing, Sondheim explained to the Institute audience that he prefers writing music to writing lyrics, where "you can't get away with much." Simple, unpoetic words often work best for musical theater, he said, leaving the music to enliven them. "You don't read, 'Oh what a beautiful morning, oh what a beautiful day, I got a beautiful feeling, everything's going my way' and get any kind of thrill," he said. "But you set it to Richard Rodgers's music and it's a whole other matter. Then the balloon lifts off the ground, then you're soaring, and that's the poem."

Writers Conversations may be viewed online at http://video.ias.edu/air. ■

BENTLEY DREZNER

Derek Bermel (right), the Institute's Artist-in-Residence, spoke with Stephen Sondheim in a Writers Conversation in November.

The Institute Letter

IAS

Fall 2011

SERGE J.-F. LEVY

This photo of Ian Wei, Member in the School of Social Science, belongs to a portfolio of images taken at the Institute in 2009–10, which are included in ***A Community of Scholars: Impressions of the Institute for Advanced Study*** (see article, page 5), along with essays by current and former Faculty and Members. The book, recently published by Princeton University Press, explores the spirit of curiosity, freedom, and comradeship that is a hallmark of the Institute's community of scholars. It depicts scientists and scholars wrestling with deep mysteries in an effort to further our understanding of the physical world and of humanity—work that forms the basis and influences the course of contemporary thought, as articulated in the articles included in this issue.

Morals and morality are not straightforward concepts, writes **Didier Fassin**, James D. Wolfensohn Professor in the School of Social Science, who examines how moral issues have become increasingly prominent in contemporary societies and discusses the specific problems they pose to the social sciences. Studying the way in which institutions, such as the police, justice, prison, social work, and mental health, treat their public, he analyzes how their practitioners both shape and are shaped by the complex and sometimes contradictory moralities at work in public discourses and public policies.

Against the backdrop of the current turbulence in the Middle East, **Glen W. Bowersock**, Professor Emeritus in the School of Historical Studies, describes the rise and fall of a late antique Jewish kingdom along the Red Sea in the Arabian peninsula and takes into account a long-neglected factor in the collapse of the Persian empire before the Byzantines, as well as the rise of Islam.

In mathematics, the continuum hypothesis, first stated by Georg Cantor in 1878, proposes that there are only two infinite assemblages of numbers, the countable and the continuum. More than a century later, **Juliette Kennedy**, a Member in the School of Historical Studies, describes the role that the late Kurt Gödel, a Member and Professor in the Institute's School of Mathematics, continues to play in the resolution of the problem, and explains why mathematicians call the statement "provably unsolvable," meaning that they can prove that it is impossible to solve using current methods.

In quantum theory, Heisenberg's uncertainty principle, which states that both the position and momentum of a particle cannot be measured simultaneously, likewise demonstrates a limit to our knowledge. As Heisenberg put it in 1927, "the more precisely the position is determined, the less precisely the momentum is known in this instant, and vice versa." **Jeremy Bernstein**, a Member in the School of Mathematics in 1957–59, describes the foundations of quantum theory and persistent disagreements as to what the theory means.

IAS
The Institute Letter

Fall 2011

Institute for
Advanced Study
Einstein Drive
Princeton, New Jersey 08540
(609) 734-8000
www.ias.edu